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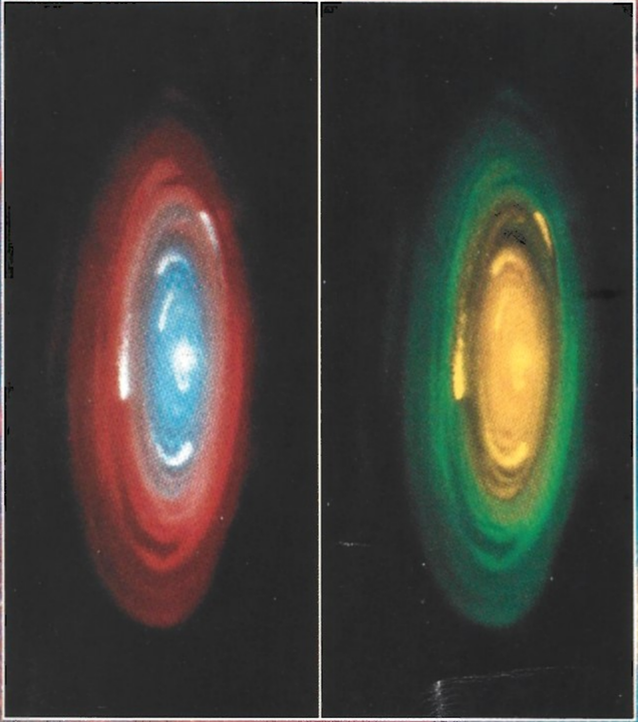

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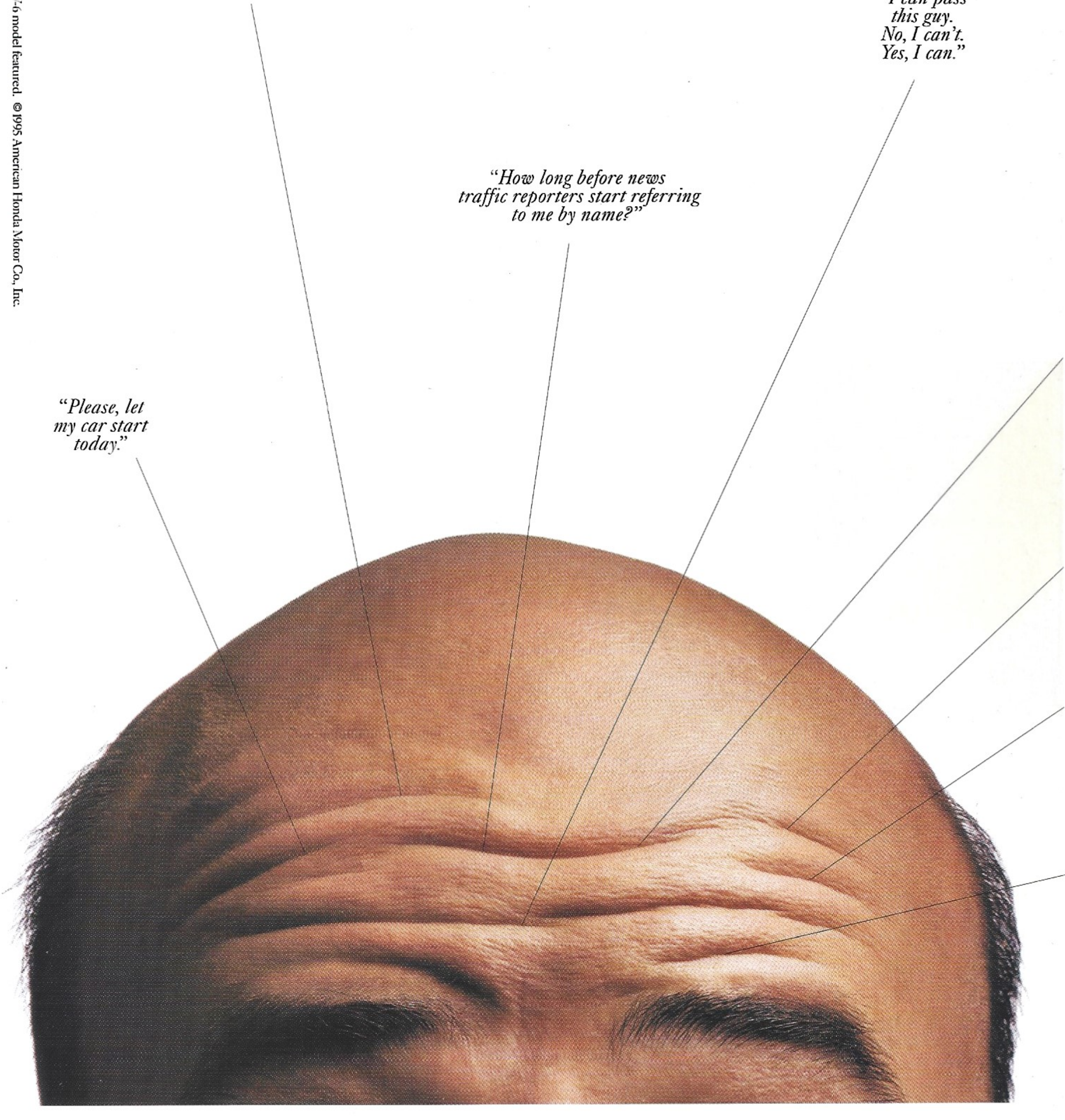

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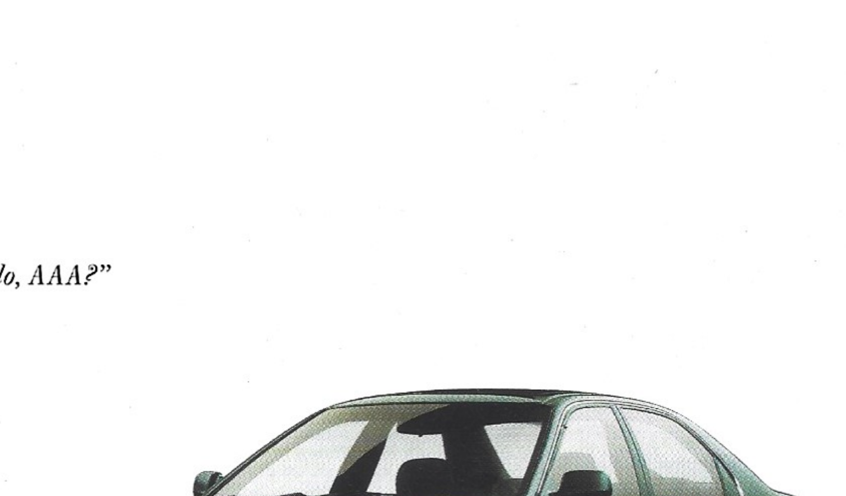

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April 1996 Vol. 17 Number 4

COVER STORY

72 **The Antimatter Mission**

BY GARY TAUBES

We are made of matter. Our planet is made of matter. So are our sun, our galaxy, our galactic supercluster. But could there be antimatter stars shining in some far-off anticorner of the universe? Thanks to a physicist's curiosity and NASA's needs, we may soon find out.

FEATURES

50 **Shark Therapy**

BY CATHERINE DOLD

Catch some sharks—a lot of them, 100,000 or so. Slice off the flesh; grind the cartilage-rich heads and spines into powder; feed the powder to cancer patients. There's no evidence this will work against cancer, but it is a proven recipe for quick profits—and environmental disaster.

60 **A Thousand Diving Robots**

BY ROBERT KUNZIG

We send robots to explore other planets—why not our own? Why not a fleet of a thousand cheap ones cruising around the ocean, buzzing the seafloor volcanoes, porpoising through the currents—and doing the work of a thousand ships?

80 **The End of the Self**

BY SARAH RICHARDSON

A former cocktail waitress takes on the fundamental tenet of immunology: that the immune system's job is to attack anything that is "nonself." Maybe, says Polly Matzinger, it has more sense than that. Maybe it only responds to clear and present danger.

COMMENTARY

42 **Ten Myths of Population**

BY JOEL E. COHEN

With 5.7 billion people now on Earth, and 250 more born every minute, it's critical that we understand the dynamics of human population growth. Yet we cling to a host of half-truths and inventions.

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Tripping *T. rex;* flipping neutrinos; Schmedly stays upright; surfing clams; face-time with Betelgeuse; Japanese smog collectors; how your throat says *aah;* deconstructing Barbie; the joke particle; and more.

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They're everywhere.

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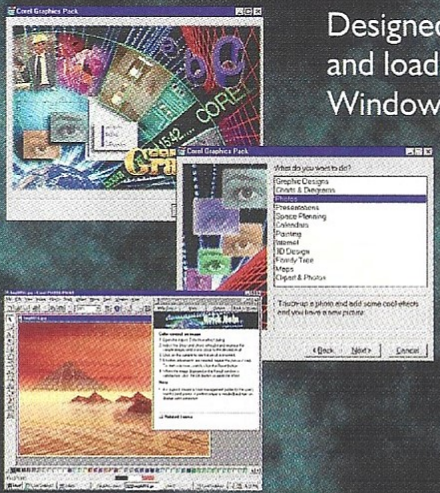
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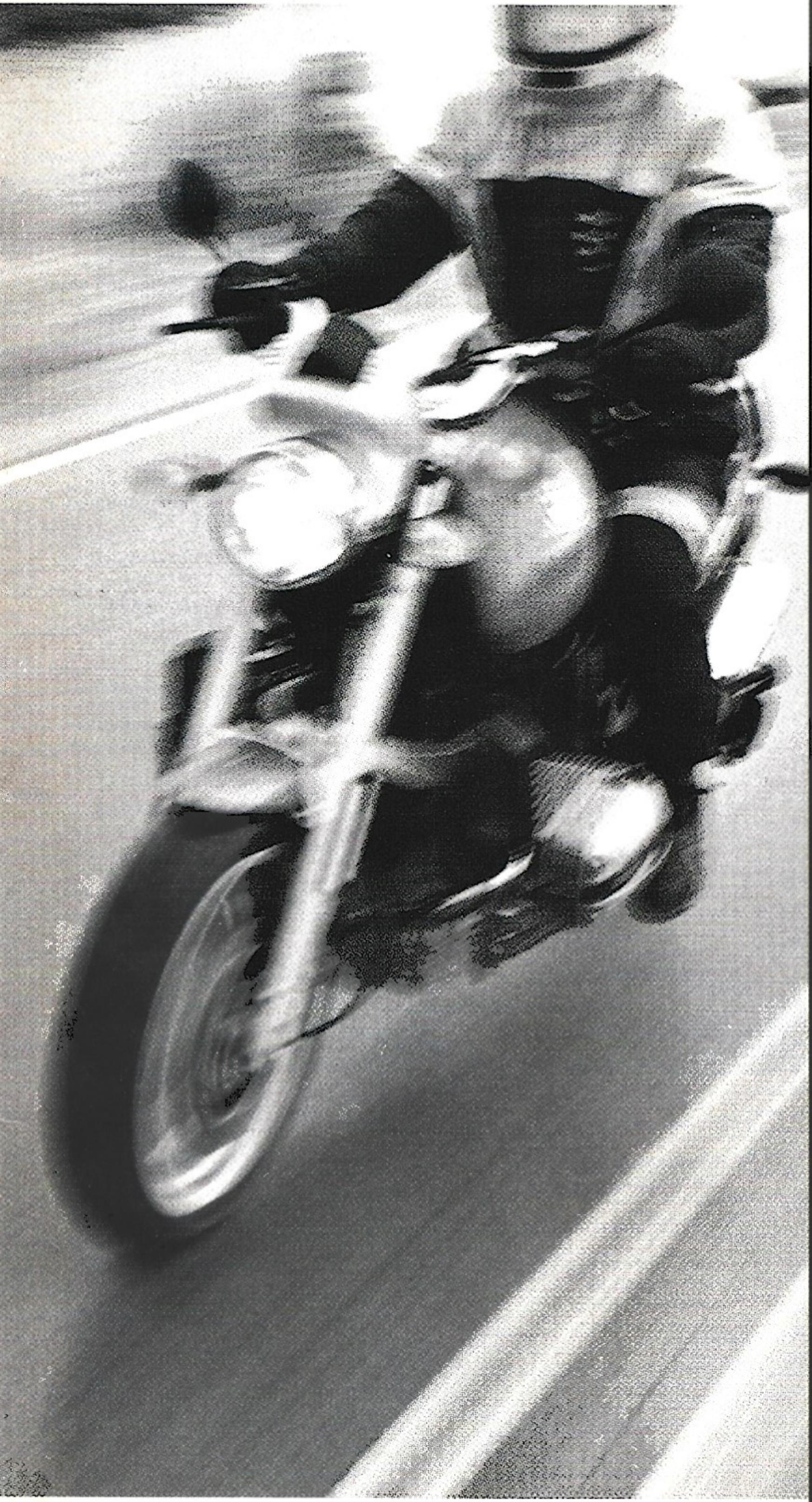

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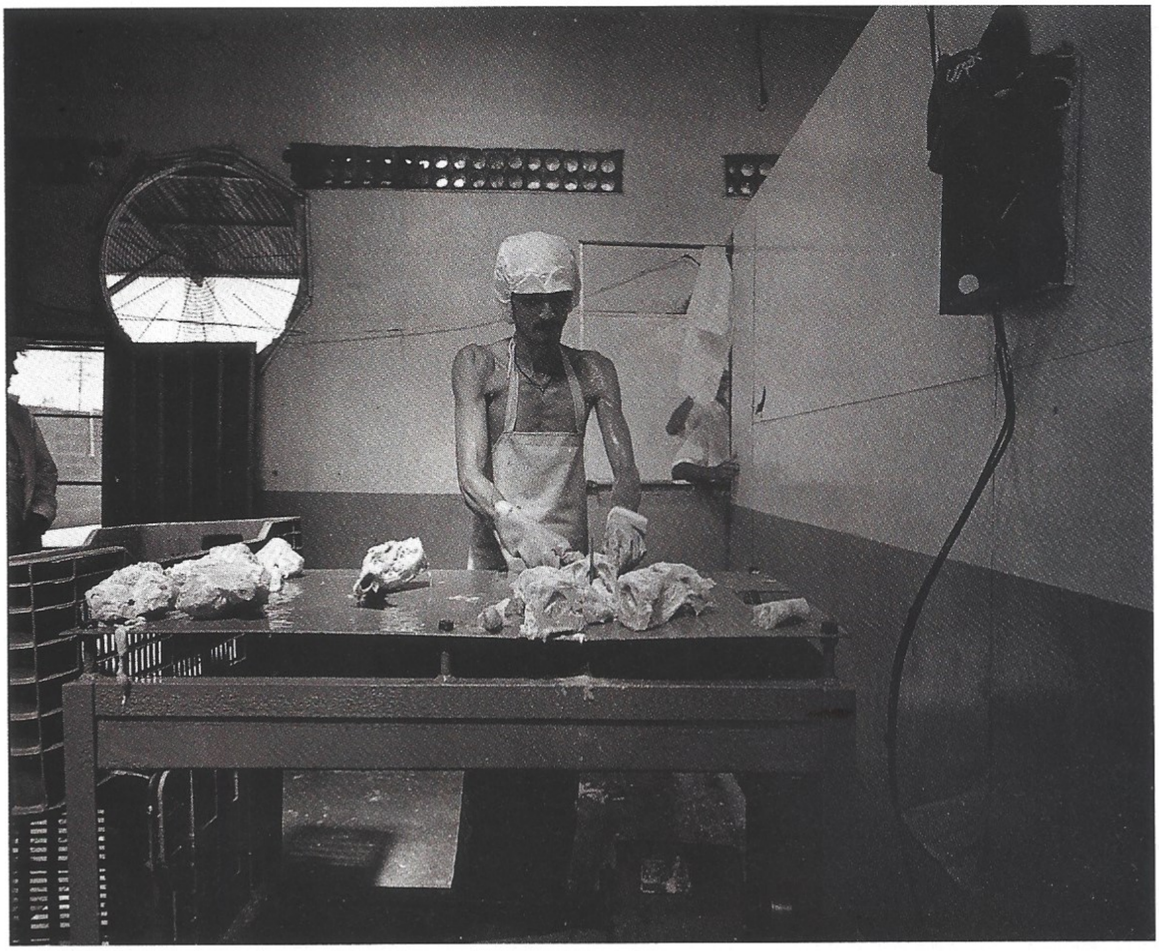
FROM THE EDITOR

Anatomy of a Health Fad

BY PAUL HOFFMAN



WELCOME TO PUNTARENAS, COSTA RICA. You won't find it in most tourist brochures, there's no Club Med, and no archeological find has put it on the map. But the town's economy has been fueled by one of the biggest health fads since laetrile: using shark cartilage to cure cancer, though the remedy is unproved. Thousands upon thousands of sharks are pulled from the waters off Costa Rica. Their skulls and spines are then pulverized and put into capsules that fetch serious dollars as anticancer pills in American health food stores. The pills are giving false hope to cancer patients and helping drive sharks toward the endangered list. For our story "Shark Therapy," on page 50, we sent writer Catherine Dold and photographer Max Aguilera-Hellweg to the shark shops of Puntarenas.

This month marks the premiere on the Discovery Channel of our new weekly prime-time science series, *Discover Magazine*. The show airs every Sunday, starting April 7, at 8 P.M. (eastern and Pacific time). Like the print version of DISCOVER, the TV show will cover everything under the sun in science—and many things beyond the sun. I think we've created a show that is both informative and entertaining, but you be the judge. Watch *Discover Magazine*, then drop me a note telling me what you think.

Paul Hoffman

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(*Commentary*, page 42) is professor of Populations at both Rockefeller University and Columbia University in New York City. His article is based in part on his new book, *How Many People Can the Earth Support?*, just published by W. W. Norton & Company.

CATHERINE DOLD
(*"Shark Therapy,"* page 50) is a freelance writer who has "escaped New York" for Boulder, Colorado. "I've written about endangered species and the wildlife trade a lot," says Dold, "and I don't think anyone really cared much about sharks before. But seeing those shark heads in vats of ice was really a shock for me. It was no longer an abstract thing in a far-off country; it made it very real."

ENRICO FERORELLI
(*"A Thousand Diving Robots,"* page 60, photographer) is a photojournalist who lives in New York City. A two-time recipient of the Gold Medal of the World Press Photo, Ferorelli has recently photographed subjects as varied as isolated Amazonian tribesmen and residents of a retirement home for opera singers in Milan. "I am against specialization," says Ferorelli. "Photography is like looking—you go around looking at the same thing over and over again, you go nuts."

LARRY GONICK
(*Science Classics*, page 40) dropped out of graduate school in mathematics at Harvard to take up intellectual cartooning. "Funny as math departments are," he says, "I had the sense that there was something funnier in the world"—something, perhaps, like *The Cartoon History of the Universe II: From the Springtime of China to the Fall of Rome.*

JEFFREY KLUGER
(*Light Elements*, page 34) is a contributing editor of DISCOVER. His book *Lost Moon: The Perilous Voyage of* Apollo 13, coauthored by astronaut Jim Lovell, was the basis for the movie *Apollo 13*.

ROBERT KUNZIG
(*"A Thousand Diving Robots,"* page 60) is DISCOVER's executive editor. He is writing a book about oceanography to be published by W. W. Norton & Company. In last month's issue, he wrote about mapping the ocean floor from space. ("What's so great about the land, anyway?" he says.)

CLIFFORD A. PICKOVER
(*Brain Bogglers*, page 92) is a computer scientist at IBM's T. J. Watson Research Center. He specializes in scientific visualization and the creative use of computer graphics. He is the author of several books, including *Keys to Infinity; The Pattern Book: Fractals, Art and Nature;* and *Future Health.*

SARAH RICHARDSON
(*"The End of the Self,"* page 80) is a senior editor of DISCOVER. "When I first started working on this story, I was surprised to find that linguists had written papers about the immune system," she says. "Now I understand that immune function is a signaling problem: how to ensure that the right cells get the right signal at the right time and place."

GARY TAUBES
(*"The Antimatter Mission,"* page 72) is a contributing editor of DISCOVER and the author of *Bad Science: The Short Life and Weird Times of Cold Fusion.* He is the winner of the American Institute of Physics 1995 Science Writing Award and also contributes to the *Atlantic Monthly* and *Science*. In DISCOVER's February issue, Taubes wrote about how cells transmit signals from the outside world into the nucleus.

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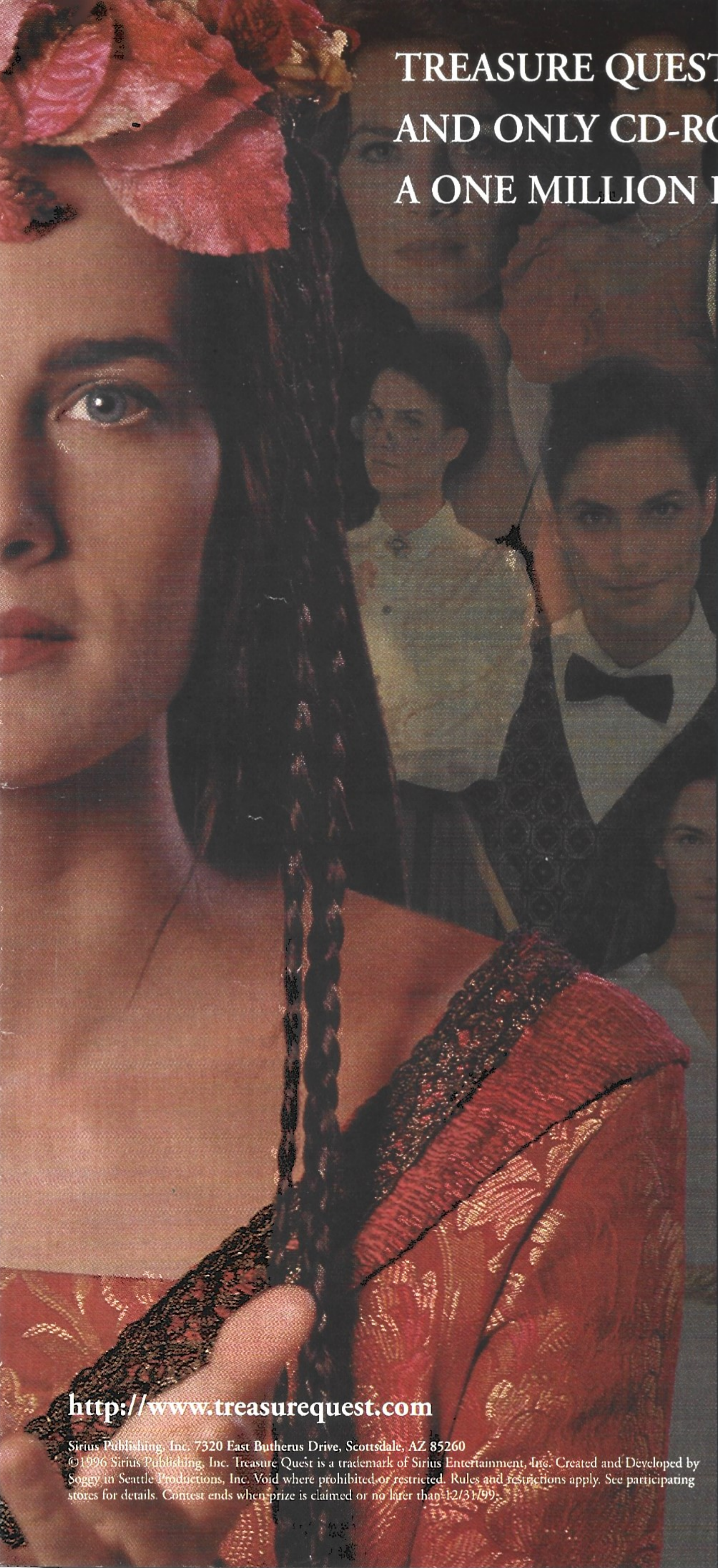

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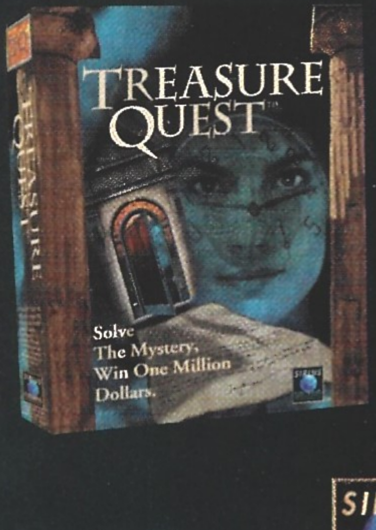

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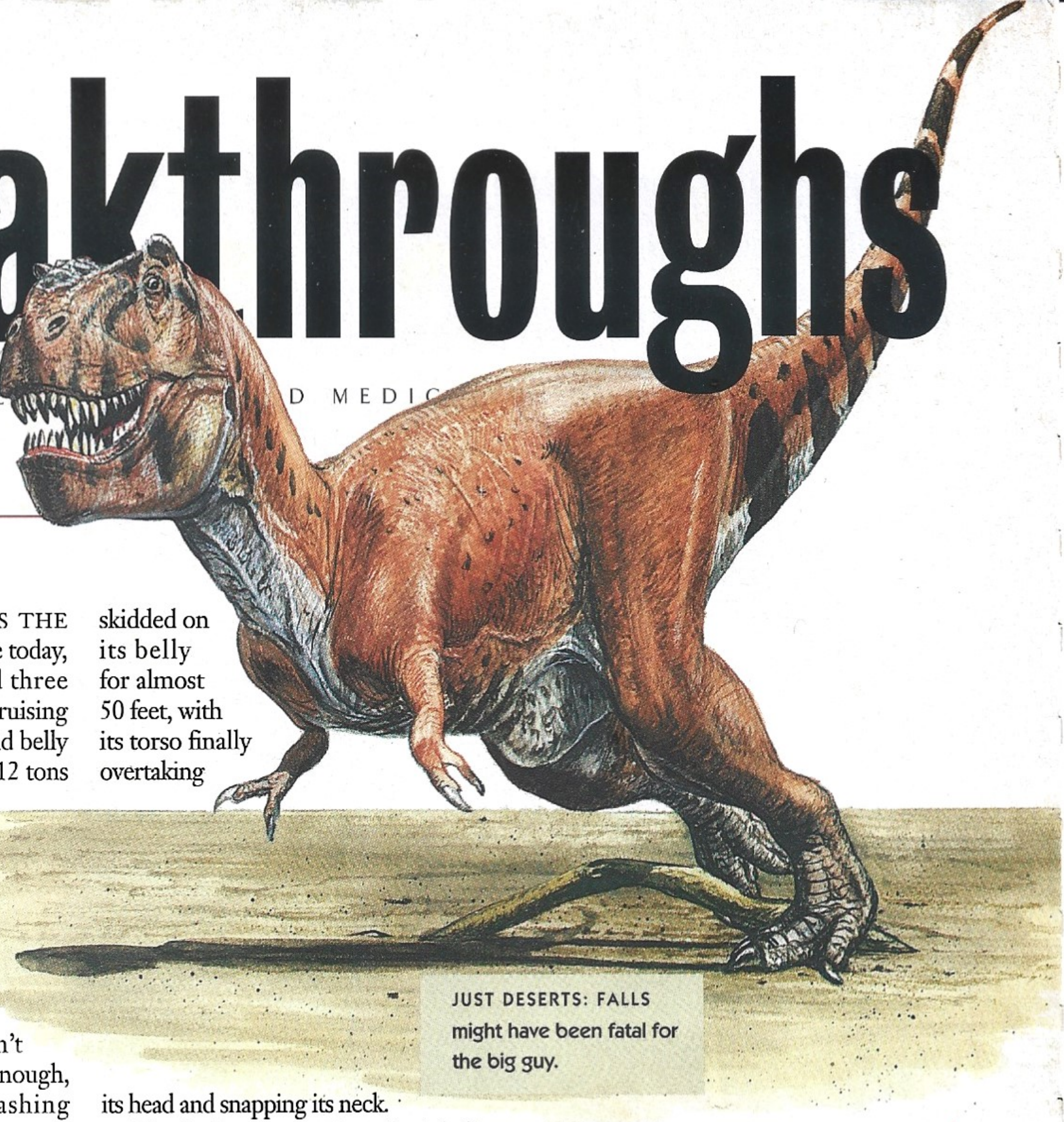


JUST DESERTS: FALLS might have been fatal for the big guy.

EVOLUTION

Tyrannosaurus wrecks

THE WHITE RHINOCEROS IS THE biggest galloping mammal alive today, typically weighing in at around three tons. If it were to stumble while cruising along at 16 miles per hour, it would belly flop to the ground with a force of 12 tons and probably suffer a substantial boo-boo or two. The fate of a tripping *Tyrannosaurus rex*, though, could easily have been far worse. It was roughly twice as heavy as a white rhino, and it had the added disadvantage of being a biped: if one foot tripped and it couldn't bring the other one forward fast enough, the beast would have come crashing down, without forelimbs strong enough to break its fall, and with its face, starting from 12 feet up, having plenty of time to gain speed before impact.

Paleontologist James Farlow and physicist John Robinson of Indiana University found themselves captivated by this image while studying a model of a *T. rex* made from a nearly complete skeleton at the Museum of the Rockies. They began to wonder whether the beast could have survived a fall.

Farlow and Robinson calculate that a 6.5-ton *T. rex* charging along at 45 mph—the top speed attributed to it by some researchers—would have landed on its belly with a force of almost 80,000 pounds and received a blow to the skull of more than 30,000 pounds. Even if that didn't squash its organs and its skull, the dinosaur would then have skidded on its belly for almost 50 feet, with its torso finally overtaking its head and snapping its neck.

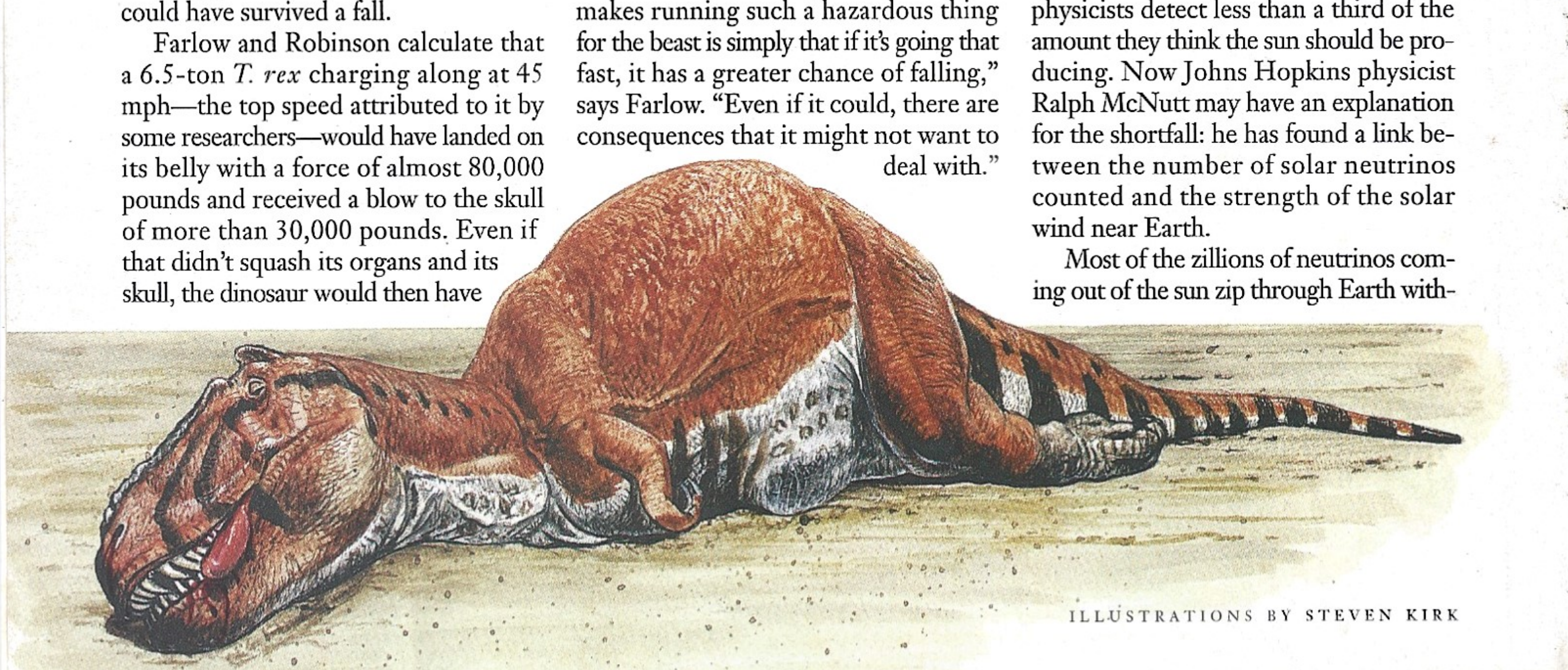
The Indiana researchers don't believe *T. rex* ever got close to 45 mph. Their examination of the tyrannosaur's thighbone and hip joint suggests that its bones would only have been strong enough to withstand the normal stresses of running at speeds of up to 25 mph, roughly matching Carl Lewis. But they argue that *T. rex*, knowing that any fall might kill it, would probably not have dared much more than 15 mph. "Part of what makes running such a hazardous thing for the beast is simply that if it's going that fast, it has a greater chance of falling," says Farlow. "Even if it could, there are consequences that it might not want to deal with."

PHYSICS

Flipping Neutrinos

NEUTRINOS ARE WISPY SUBATOMIC particles with no electric charge and little, if any, mass. They're created during nuclear reactions such as those that power the sun. Given the size of the sun, it should produce lots of neutrinos—and it does. But after 30 years of looking, physicists detect less than a third of the amount they think the sun should be producing. Now Johns Hopkins physicist Ralph McNutt may have an explanation for the shortfall: he has found a link between the number of solar neutrinos counted and the strength of the solar wind near Earth.

Most of the zillions of neutrinos coming out of the sun zip through Earth with-



ILLUSTRATIONS BY STEVEN KIRK

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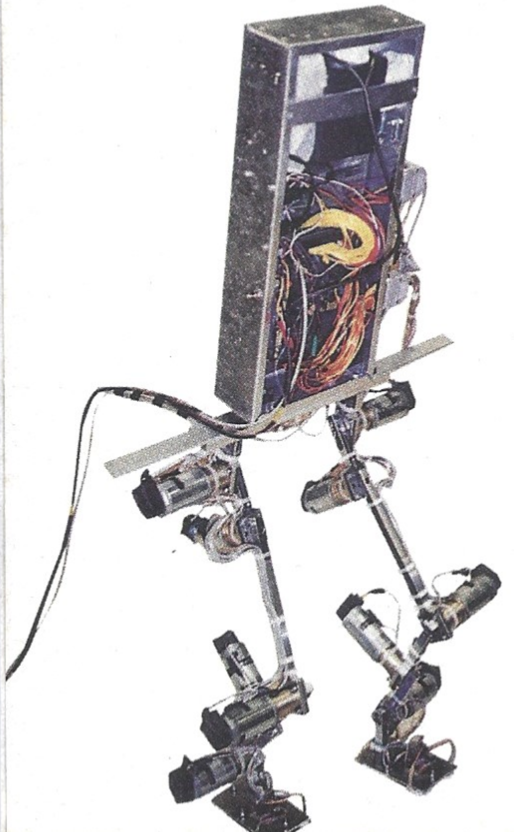
One Small Step for Schmedly. . .

Schmedly, the walking robot shown here, stands about three feet tall, weighs 25 pounds, and has a disembodied brain in the form of a desk-top computer. While Schmedly is not the first walking robot, it is the first to learn to walk by experience, according to its inventor, Tom Miller, an engineer at the University of New Hampshire. Unlike other walking robots, Schmedly doesn't follow a rigid program. Miller gives the robot a minimum of instructions—it knows, for example, to take its weight off a foot before lifting it, then move the foot forward, set it down, and repeat with the other foot. But Schmedly has to figure out how far to lean, how high to lift its feet, and where to put its hips in relation to its feet. To that end, the robot has four sensors on each foot that tell it exactly how much weight each part of the foot bears. Schmedly also has an "inner ear" for balance, in the form of accelerometers that measure gravity and motion. The robot's gait is quite different from a human's, and a spotter is on hand to catch it in the inevitable event of a fall. "It has a drunken sailor look," says Miller. "It sways a lot."



out stopping; researchers must go to great lengths just to detect a handful. In his study, McNutt used data from a 30-year-old neutrino detector—a 100,000-gallon tank of cleaning fluid located almost a mile underground in the Homestake Gold Mine in South Dakota. Neutrinos from the sun occasionally hit chlorine atoms in the fluid, converting them into a radioactive—and detectable—form of argon. The Homestake measurements are what first made researchers realize that they had a solar neutrino problem.

The most popular solution to that problem lately has been a theory called neutrino oscillation. There are three types of neutrino—electron, muon, and tau—and the Homestake detector detects only the first. According to the neutrino oscillation theory, some of the sun's electron neutrinos spontaneously transform into one of the two undetectable types before they leave the sun, thus producing what looks like a shortfall at Homestake.

McNutt's new observations support an alternative theory. After comparing the Homestake data with 19 years' worth of satellite measurements of the solar wind—which consists of electrically charged particles like protons and electrons—McNutt has found that the neutrino counts have risen and fallen as the solar wind has. Since the strength of the solar wind is probably controlled by the sun's magnetic field, McNutt believes his observations suggest that the field is also affecting the neutrinos. As they pass through the "convective zone" below the sun's surface, he suggests, the field may flip the magnetic polarity of some of them, making them undetectable.

That would require neutrinos to have magnetism, which hasn't been observed. (On the other hand, the oscillation theory requires neutrinos to have mass, and that too hasn't been proved.) McNutt's theory that neutrino magnetism can be changed will be even harder to verify in the lab. "In the sun, we're dealing with a magnetic field perhaps 10,000 times the strength of Earth's magnetic field, over a convective zone that is 120,000 miles thick," he says. "There is no direct way of re-creating that on Earth."

ANIMALS

Clam Dancing

ALTHOUGH IT IS PROBABLY NOT possible to underrate the intelligence of clams, their athletic skills apparently deserve more respect. Olaf Ellers, a marine invertebrate biomechanic at the University of California at Davis, has found that some clams jump out of the sand and ride the waves, the better to stay near the water's edge as the tide changes.

Most researchers who have studied clam locomotion (they are not a large group) hold that waves erode clams from the sand, carrying the mollusks along. And indeed, that is true for most clams. But according to Ellers, coquina clams in North Carolina are not so passive. They surf and seek out the largest waves.

NO STICK-IN-THE-MUD: Streamlined coquina clams can surf.

Ellers took 234 dead clams and painted them pink. During an ebb tide, he planted each one in the sand in shallow water about an inch away from a live clam painted red. When the tide was out, he counted how many were left on the beach. The results: Fifty to 80 percent of the dead clams were still buried, compared with 5 percent of the live ones. The live clams had propelled themselves out of the sand with their muscular "foot" after a retreating wave had passed over them, and had let it carry them seaward. "Their foot is like our tongue," Ellers says. "It's as if you had your head in the sand and stuck your tongue out and pushed against the sand with it."

During a rising tide, Ellers observed clams in the sand jump in front of a breaking wave and then ride the churning water up the beach. The clams chose only the waves that would carry them farthest—a strategy that no doubt saves them

TOP: Olaf Ellers; BOTTOM: courtesy T. Miller

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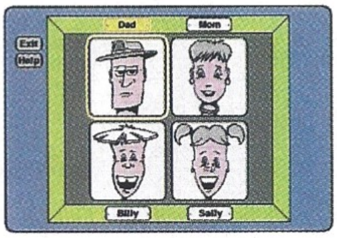

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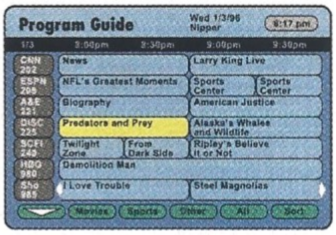

Program Guide

Wed 1/3/96
Nipper

8:17 pm

1/3	8:00pm	8:30pm	9:00pm	9:30pm
CNN 202	News		Larry King Live	
ESPN 206	NFL's Greatest Moments		Sports Center	Sports Center
A&E 221	Biography		American Justice	
DISC 225	Predators and Prey		Alaska's Whales and Wildlife	
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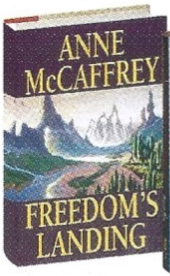
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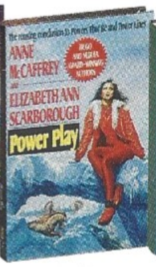
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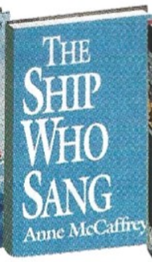
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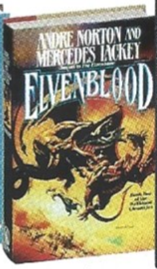
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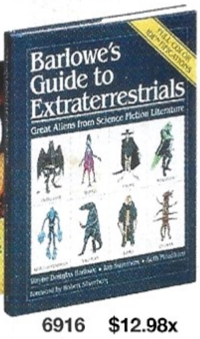
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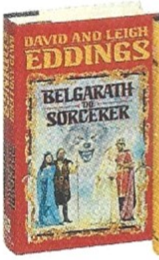
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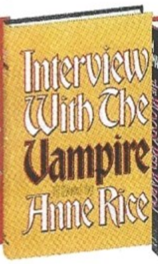
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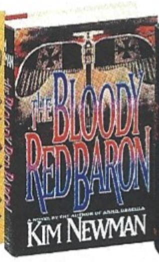
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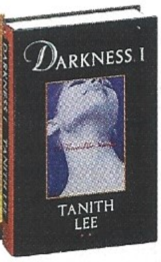
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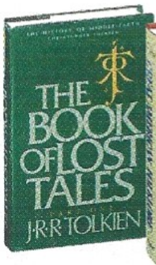
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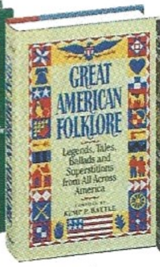
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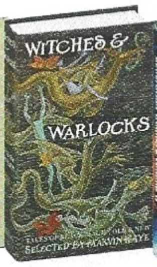
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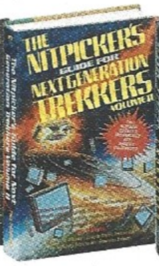
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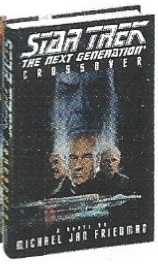
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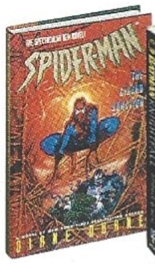

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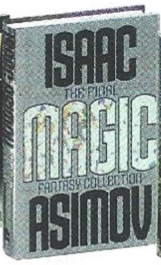
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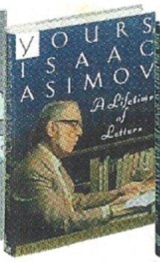
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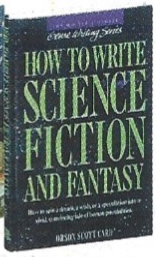
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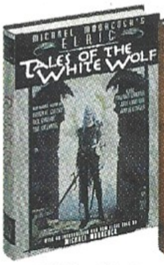
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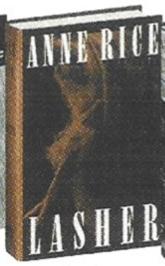
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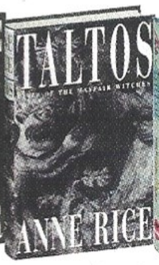
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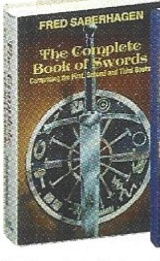
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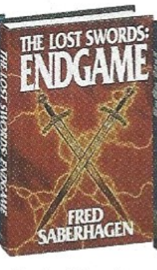
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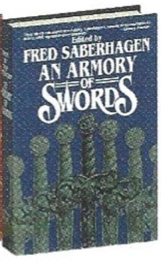
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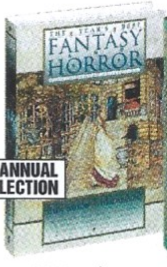
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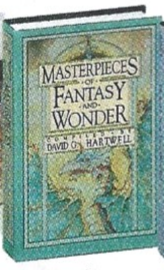
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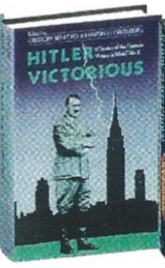
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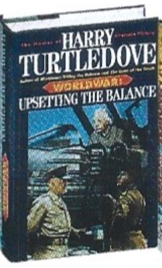
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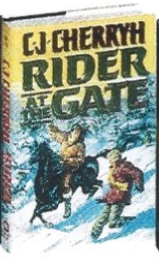
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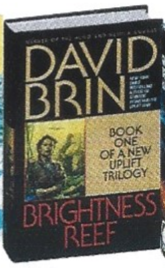
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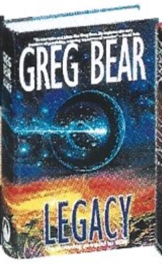
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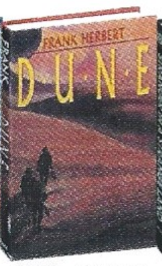
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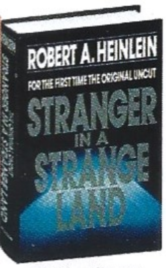
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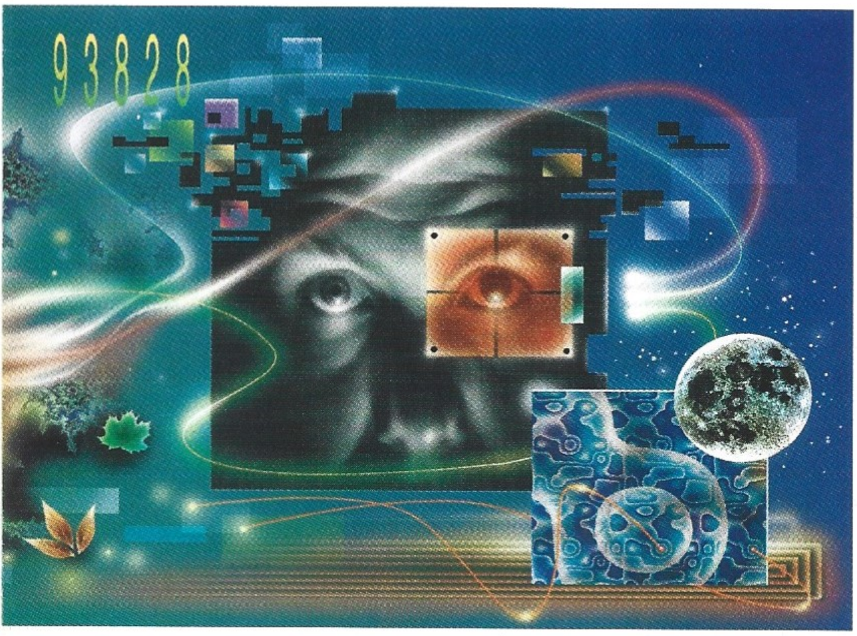

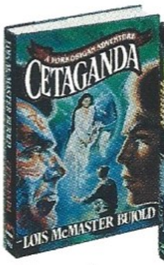
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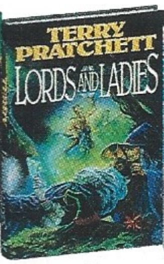
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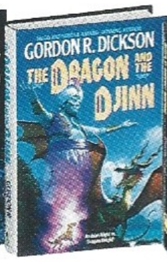
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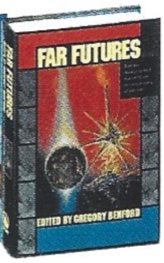
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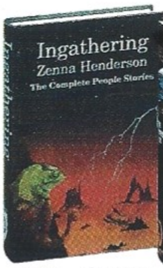
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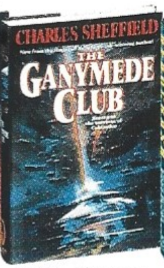
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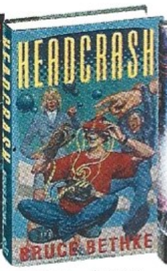
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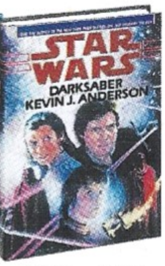
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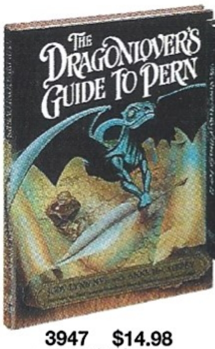
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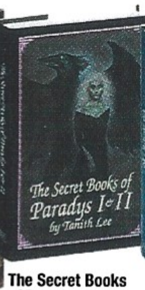
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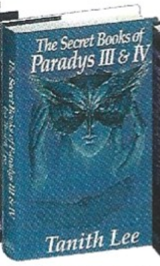
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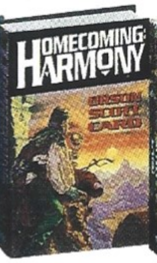
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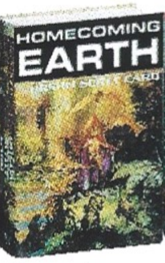
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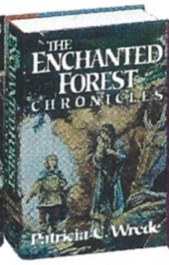
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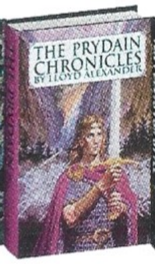
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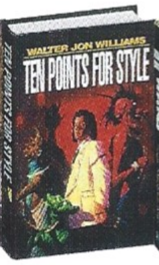
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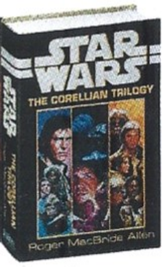
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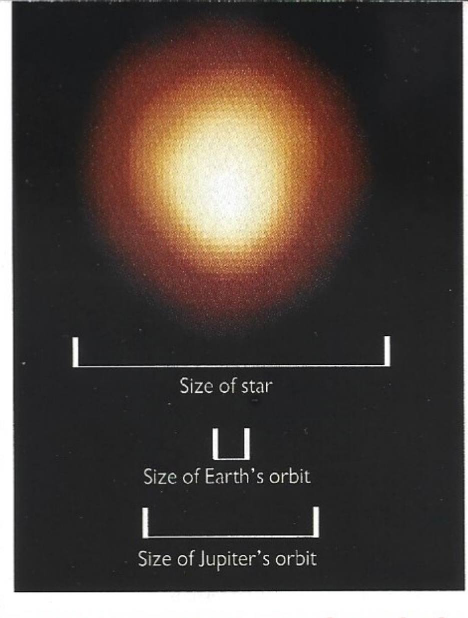
The Face of Another Sun



Most stars are so distant that even the largest telescopes resolve them only as pinpoints of light. But then most stars are not Betelgeuse, a red supergiant 500 light-years away, familiar as the star marking the shoulder of Orion the hunter. And most telescopes don't float above Earth's blurring atmosphere as does the Hubble Space Telescope. In this, the first direct, detailed image of a star other than the sun, the hot outer atmosphere of Betelgeuse is shown to stretch nearly a billion miles across—if it were our sun it would have swallowed Jupiter. Most of this outer atmosphere has a temperature of around 9,000 degrees Fahrenheit, which is 1,000 to 2,000 degrees cooler than the sun's surface temperature. But whereas the sun radiates more or less evenly across its entire surface, Betelgeuse has a 12,000-degree hot spot that occupies about 10 to 20 percent of the star's disk—and baffles astronomers. "The dominance of this one very hot spot, from which most of the radiation is emerging, is totally different from what we see in the sun," says Andrea Dupree of the Harvard-Smithsonian Center for Astrophysics. The spot may be connected to Betelgeuse's 420-day pulsation cycle or to some unknown magnetic field effect.

energy. But how do they pick the waves? In an aquarium in his lab, Ellers played them wave sounds and found that most jumps coincided with the pre-arrival rumble of the loudest waves. Ellers guesses the clams may sense the vibrations with small, hairlike cilia on their "neck," which is really the siphon they breathe through.

Surfing keeps coquinas near their food—the breakers stir up plant and animal matter that the clams filter out of the water. But they may also be trying to keep out of the sun. Unlike clams in New England, which rest comfortably in cool, wet sand between tides, these coquinas live on hot, dry beaches. "If you heat them up, they die," says Ellers.

TECHNOLOGY

Smog Collectors

TOKYO, LIKE OTHER MAJOR CITIES, has too many people, too many cars, and smog. But Koji Takeuchi thinks he can alleviate the smog problem. Takeuchi, a chemist at the National Institute for Resources and Environment in Tsukuba, wants to line Japanese highways with smog-collecting panels he and his colleagues have designed. Initial field tests have been promising, and Takeuchi says the panels should be inexpensive to install and maintain.

PANELS ALONG A Japanese highway pull smog out of the air.

A bit over a foot long, the panels are made of Teflon fibers that have been mixed with carbon powder and titanium dioxide (a chemical commonly found in paint) and rolled into sheets. Sunlight striking a panel boosts electrons in the titanium dioxide to higher energy levels, making the molecules more reactive. The molecules grab oxygen and water vapor from the air and hold them on the panel. The water and oxygen then react with nitrogen oxides and sulfur oxides—smog components released in car exhaust—that drift over the panels. The carbon, Takeuchi believes, also attracts pollutants, holding on to them temporarily until they eventually react with the water vapor and oxygen.

The reaction converts the pollutants into nitric acid and sulfuric acid, which collect on the surface of the panel. About 60 percent of the acids run off the panels when it rains and drain into a ditch filled with lime, where they are neutralized. The remainder of the acids stick to the panels, which need to be cleaned periodically.

Of course, Takeuchi says, the panels are not the ultimate answer to smog control. And they may not work everywhere. For example, some parts of the American Southwest may be too dry. Without rain, the panels will become clogged with acidic gunk. "The sheets require sunlight and rainwater to work," says Takeuchi. "Fortunately, we have a lot of rain in Japan."

In a field test in Tokyo, the filters lowered nitrogen oxide and sulfur oxide levels along a 30-foot stretch of highway by at least 20 percent, says Takeuchi. He says he and his colleagues have recently made their sheets three times more efficient—at least in the lab. "Even a 20 percent reduction of nitrogen oxide will greatly increase the areas where the environmental standards are satisfied in Japan," says Takeuchi. In the future, he hopes to use the filters in tunnels with artificial sunlight and to coat parts of buildings and highway dividers so they can act like filters.

ASTRONOMY

The Vacant Interstellar Spaces

HOT, BRIGHT STARS FILL THE ARMS of spiral galaxies. But what about the dark gaps between the arms? Are they filled with dark dust, as some researchers have supposed? Astronomers at the University of Chicago and the University of Alabama say no: they've found evidence that the gaps between spiral arms are indeed as empty as they look.

The astronomers studied pairs of galaxies in which one lies behind the other, so that the galaxies partially overlap along our line of sight. By measuring how much of the background galaxy's light made it through various regions of the foreground galaxy, they could determine where the foreground galaxy was choked with light-absorbing dust.

Most of the dust turned out to be in the bright arms; the space between the

TOP: Courtesy Andrea Dupree (Harvard-Smithsonian CfA), Ronald Gilliland (STScI), NASA, and ESA; BOTTOM: courtesy Koji Takeuchi

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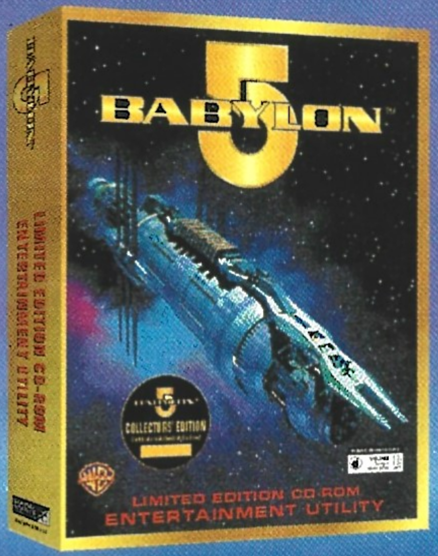

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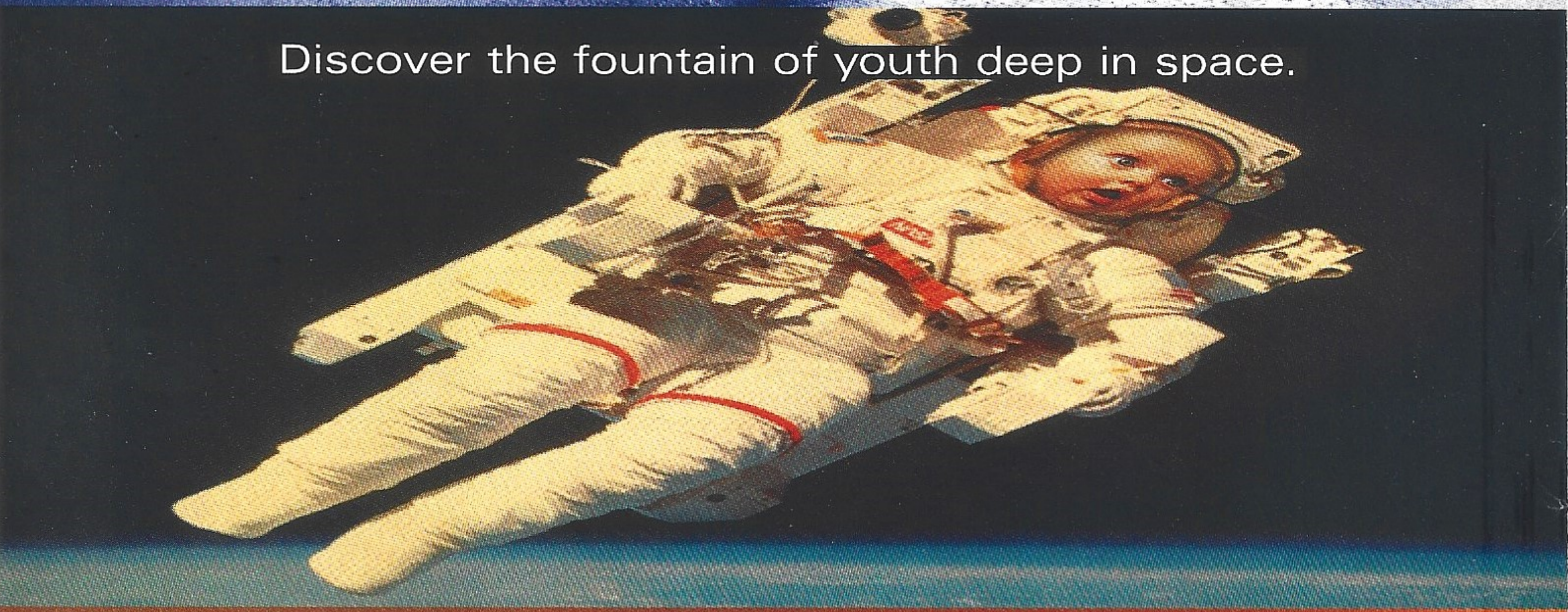
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LIGHT FROM THE GALAXY behind shows dust in the galaxy in front.

arms and the outer parts of galactic disks were much more transparent. "We find that it's not unusual for only 15 to 20 percent of the light from a background galaxy to make it through a spiral arm," says Alabama astronomer William Keel. "But at a location corresponding to where we are in the Milky Way, you'd have 80 percent making it through." The solar system lies in a gap between two of the Milky Way's spiral arms—which is fortunate for astronomers. If we were inside a dusty arm, says Keel, we might not be able to see other galaxies at all.

Why does the dust end up in the arms? Astronomers believe that "density waves"—in effect, stellar traffic jams—concentrate the dust there. Clumps of stars and dust create high gravity regions that suck dust in and delay its motion through the galactic disk. This compressed gas creates a wave of star formation that adds the bright but ephemeral stars that make spiral arms so striking.

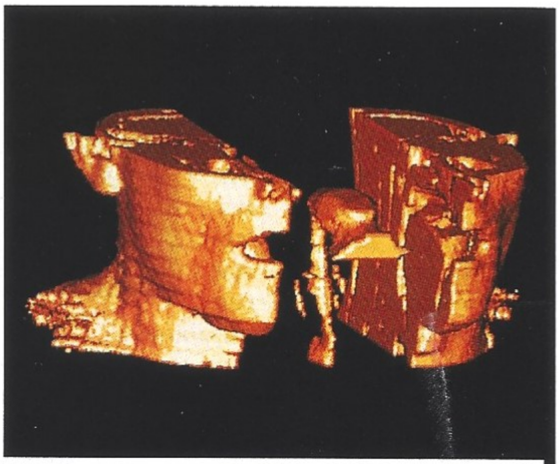
BIOLOGY

Deliberate Resistance

IN THE BACTERIAL WORLD, NECESSITY seems to be the mother of mutation. Genetic mutation in an organism had always been thought to be an essentially random process. But within the past few years, researchers have found that starving *E. coli* can increase their mutation rate, thus increasing their chances of undergoing an "adaptive" mutation that will allow them to eat some otherwise indigestible food. Now microbiologist Joel Weiner and molecular geneticist Susan Rosenberg of the University of Alberta report that perfectly well fed bacteria may use the same strategy to develop resistance to antibiotics.

Citrobacter freundii, the bug they studied, causes a host of infections of the lung, bladder, and stomach. Normally it is vulnerable to penicillin. But there are

Say "Aah"



The sounds we voice depend on how we manipulate the tube defined by the mouth and throat. When making a sound like eee, for example, the mouth constricts but the throat opens. In a sound like *aah*, the mouth opens and the throat constricts. To study precisely how we make sounds, speech scientist Brad Story of the University of Iowa lay in a magnetic resonance scanner for three seven- to eight-hour sessions. "I don't think I would do it again," he says. Story made 22 different vowel and consonant sounds while the scanner recorded the shape of his vocal tract and then processed the images to represent the tract as a solid tube, dissected from the skull. When he measured the cross-sectional areas of the tube for each sound and fed the information into a speech simulator, the voice it produced sounded remarkably like his own. Story next hopes to create a "virtual" vocal tract on a computer to study the nuances of the voice. "We might learn how singers can enhance their performance, or how a cleft palate affects the voice," says Story. "In speech it's very difficult to get at a lot of things that we want to understand, because humans aren't willing to have needles and probes stuck through their vocal tracts."

TOP: Courtesy Raymond White III, William Keel, and Christopher Conselice; BOTTOM: courtesy Brad Story

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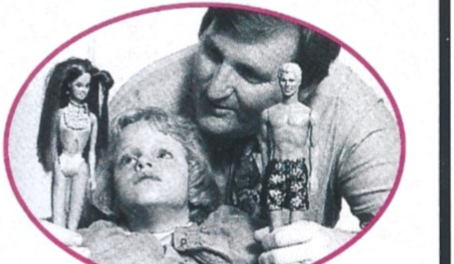
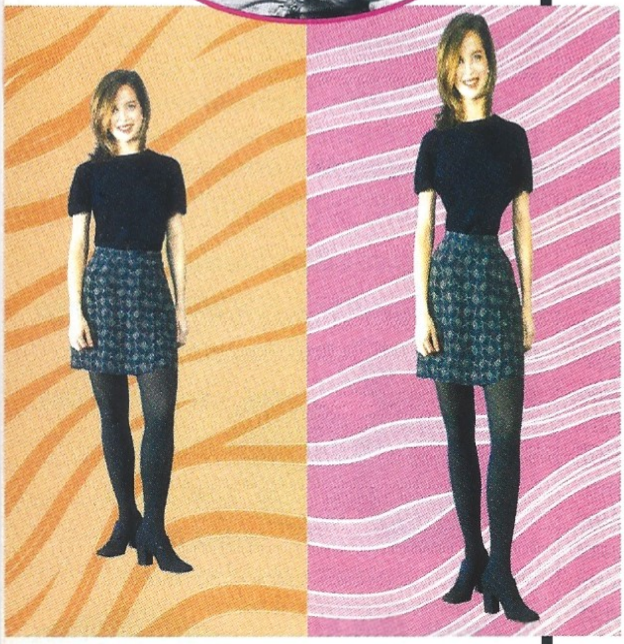




Laws of Physiques

Since she first sashayed onto the American scene in 1959, Barbie has reproduced more than 800 million times. To say that she sets an impossible standard of beauty is obvious, but Kelly Brownell, a psychologist at Yale, has determined just how impossible. According to his calculations, if an attractive, healthy woman like the one shown here (left) keeps her hips the size they are, she would have to gain nearly a foot in height, add four inches to her chest, and lose five inches from her waist to become a life-size Barbie (right). Brownell worries that in a country where anorexia is not uncommon, Barbie may convey an unhealthy message to children. "I don't think that there are people that have those proportions," he says. "But if every Barbie was taken off the market, would this help body image in Americans? I don't know, because the message to be thin and disproportionate is pretty widespread." Brownell is shown here with his seven-year-old daughter, who owns six of the dolls.

strains of citrobacter that have the ability to resist a class of penicillin drugs called cephalosporins—because they have undergone mutations that allow them to crank out unusually large amounts of an enzyme, beta-lactamase, that degrades the drugs. The resistant strains first arose, Weiner says, when serious outbreaks of citrobacter among hospital patients were treated with large doses of cephalosporins.

In laboratory experiments, Weiner and Rosenberg found evidence that the resistance-conferring mutations happen only in citrobacter that are equipped with a functioning set of DNA-recombining enzymes—the same enzymes *E. coli* use to up their mutation rate. Bacteria without the enzymes die when they're put in a nutrient solution containing cephalosporin; but some of the bacteria with the enzymes make the mutation they need, start churning out the beta-lactamase, and survive. Somehow, Weiner thinks, the presence of the antibiotic outside the bacterial cell wall must trigger the bacterium to start recombining DNA. "Our results suggest that bacteria possess the ability to alter their mutation rate in response to any kind of stress that interferes with their ability to grow," Weiner says. Whether that ability may account for some of the current increase in antibiotic-resistant bacterial strains—a major problem in medicine these days—is not yet clear.

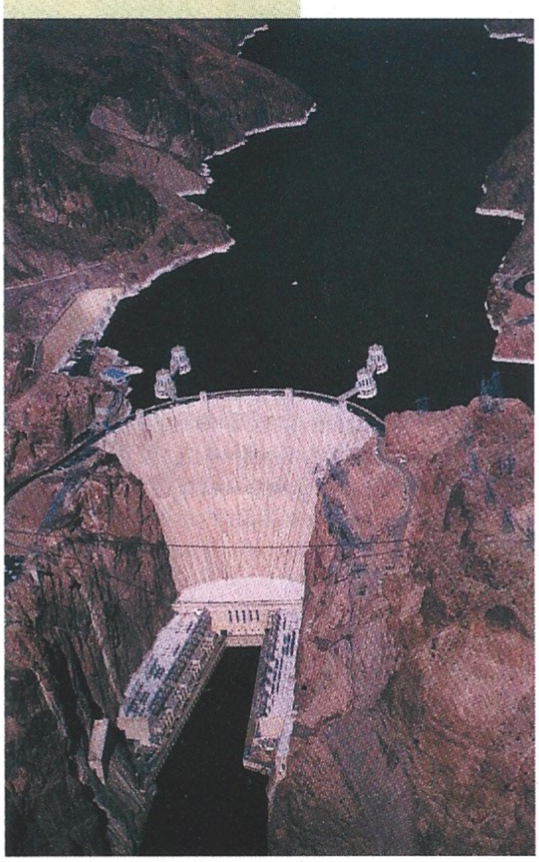
GEOPHYSICS

Speeding Up Earth

DAYS ARE NOT AS LONG AS THEY should be. Scientists know that the moon's gravity pulls on Earth and slows its rotation, so that yearly, the days get about 20 millionths of a second longer. But Benjamin Chao has discovered a countervailing effect, one that shortens the day by about .2 millionths of a second per year. Chao, a geophysicist at NASA's Goddard Space Flight Center, says humans have redistributed enough mass on Earth to affect the planet's rotation rate. How? By storing water in artificial reservoirs, most of which have been built in the past four decades.

Chao estimates that over 2 quadrillion gallons of water that would otherwise be spread evenly in oceans are in reservoirs, lowering sea levels by more than an inch. To estimate the effects of this on Earth's rotation, Chao assessed the capacity of 88 reservoirs worldwide that hold more than 2 trillion gallons, like Hoover Dam. Most of the reservoirs are in the Northern Hemisphere, he says, so there has been a net shift of water northward, away from the equator—and thus closer to Earth's axis. That makes the planet spin faster, just as figure skaters spin faster when they pull their arms in. The mass shift has also made the North Pole move about two feet toward 130°W longitude—essentially because the planet is being tipped the other way by a concentration of reservoirs in the Eastern Hemisphere, mostly in Asia. Both effects, Chao says, are probably even greater than he has estimated; the reservoirs he studied hold less than half the water dammed by humans.

RESERVOIRS LIKE LAKE Mead, behind Hoover Dam, affect Earth's spin.



TOP: Courtesy Michael Marsland, Yale University; RIGHT: © Calvin Larsen 1988/Photo Researchers

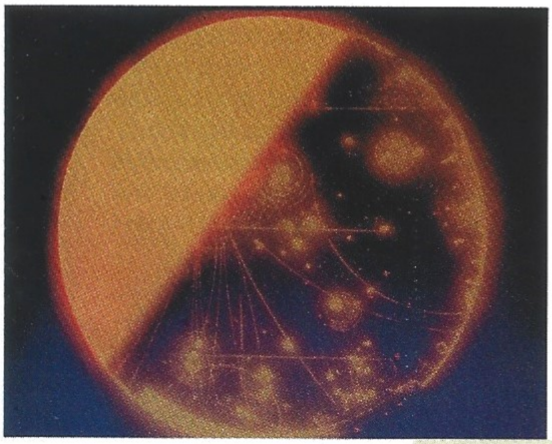
LOWER LEFT: JILL GREENBERG

Breakthroughs

PHYSICS

The Bigon

ALBERT MANQUÉ IS A PHYSICIST OF the old school. "Fifty years ago physicists could make experiments using material from the hardware store," says Manqué, who works at the Centre de l'Étude des Choses Assez Minuscules in Paris. "I too prefer to work on a small scale." His penchant for tabletop research recently paid off. He and a colleague at the center have discovered an extraordinary new fundamental particle. Although the particle exists for just millionths of a second, it is the size of a bowling ball. Its existence, says Manqué, could possibly explain a host of mysterious phenomena.

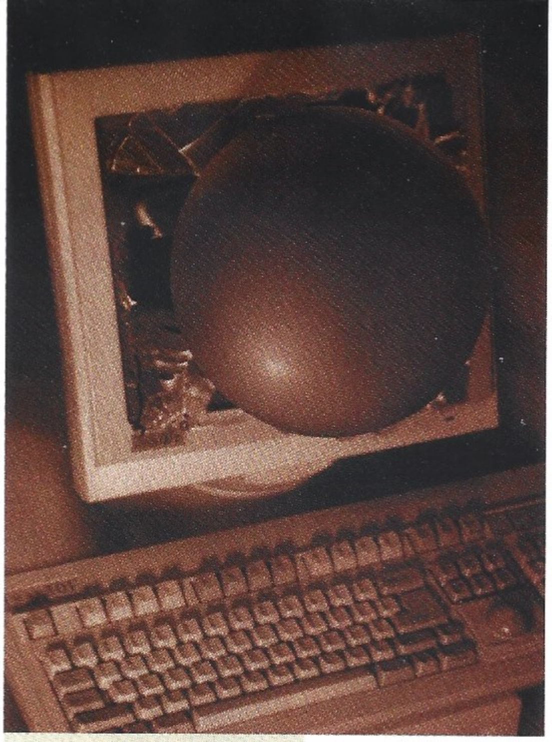


THE BIGON'S unmistakable trail (upper left) in a cloud chamber.

Manqué and his colleague Jean-Xavier Zweistein call the new particle a bigon and say its discovery was serendipitous. Their main research consists of building better vacuum tubes to replace microchips. "We are the only physicists in the world working on that, more or less," says Manqué. They were running a large current through one of their tubes when the monitor of a nearby desktop computer exploded.

"We thought it was an accident completely from the blue sky," says Manqué. "The computer was connected to an entirely separate electric circuit, so it should not have been affected. But after we bought a new one and ran current again through the tube, the new computer, it too exploded." The physicists set up a video camera and repeated the experiment—with the same explosive results. In one of the video frames a black bowling-ball-size object hovered above the wreckage of the computer. In the next frame it was gone.

The researchers believe that the electric field in the vacuum tube somehow altered the energy state of the vacuum inside the cathode-ray tube in the nearby computer monitor. No vacuum is truly empty—"virtual" particles, most of them quite small, continually burst into existence and then dissolve back into the void. The physicists believe that they accidentally generated an electric field of just the right size in the computer to nudge a new particle—a bigon—into being.



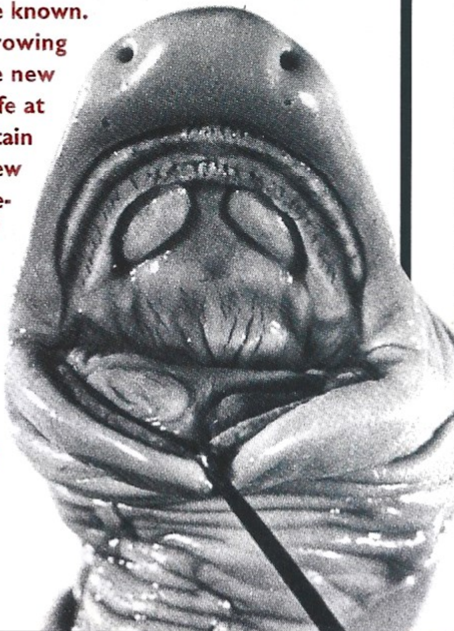
C'EST PAS VRAI! An evanescent bigon erupts in Paris.

They have since detected bigons in a specially built cloud chamber—a gas-filled detector that traces particle paths. "The bigon leaves a unique signature," says Manqué. Indeed, he thinks the new particle's signature may be everywhere in nature. "Bigons could be responsible for ball lightning, migraines, the unexplained failures of equipment and soufflés, the spontaneous human combustion—I don't know, maybe earthquakes even," Manqué says. "An archeologist colleague here at the center believes a bigon may also have brought down the walls of Jericho. You know that story, too, has never been explained to our satisfaction."

Is there any chance that the bigon is just a figment—or some kind of ridiculous April Fool's joke, as virtually all other physicists are saying? "People are so cynical," responds Zweistein. Science, he points out, routinely produces findings that seem too marvelous to be believed—and that yet turn out to be true. "Tripping dinosaurs, surfing clams—is a somewhat large particle more unbelievable than that? Or are you saying we ourselves have been duped? That I don't think. Subtle is the Lord, but he is not a kegler." ◘

Large and Lungless

This odd, Muppet-like creature floated preserved and ignored in a jar in a museum in Vienna for some 100 years until Ronald Nussbaum discovered its secrets. Nussbaum, a University of Michigan zoologist who specializes in caecilians, the little-known group of amphibians to which this beast belongs, learned of the specimen from one of his graduate students. When Nussbaum dissected the two-and-a-half-foot-long creature, he found it had no lungs. Apparently, like some salamanders, this animal absorbs oxygen and expels carbon dioxide directly through its skin. Not only is this the sole lungless caecilian, it's by far the largest lungless, four-limbed vertebrate known. Most other known caecilians are burrowing creatures, but Nussbaum believes the new specimen's bizarre features suit it to life at the bottom of cool, high-oxygen mountain streams. Researchers have created a new genus for the unique animal called *Atretochoana*, meaning "closed nostrils." Only one other specimen, collected in Brazil a few years ago, is known. Unfortunately, no records exist showing just where in Brazil the specimen was found. "The curator told us that it was collected within the last three to five years," says Nussbaum. "We're pretty sure that it isn't extinct."



LEFT: Original image © Omikron/Photo Researchers; BOTTOM: Ronald Nussbaum

TOP(2): JOHN BLACKFORD

Carbon Capital of the Galaxy

BY JEFFREY WINTERS

Carbon is the stuff of life. And our solar system seems to be much more generously endowed with it than most other parts of the galaxy.

JUST ABOUT EVERYWHERE you look in the solar system, you find carbon: from the searing atmosphere of Venus to the oily slush of Titan to the hair of the dog that bit you. In fact, carbon is the fourth most common element in the solar system after hydrogen, helium, and oxygen. And since astronomers consider our solar system to be fairly mundane, most of them assume that carbon is just as common in the rest of the galaxy. But a recent reexamination of the composition of about 200 ordinary stars in the Milky Way has shown that our sun contains much more carbon than most of its neighbors. Our sooty home is apparently something of a carbon oasis.

This new assessment of carbon's abundance comes from astrophysicists Ted Snow of the University of Colorado and Adolf Witt of the University of Toledo. They examined data from a dozen recent surveys of both young and middle-aged stars and were surprised by the paucity of carbon in these stars. "I don't think we found a single case of another star with the solar carbon abundance," Snow says.

Carbon forms from the fusion of helium nuclei in the cores of old, giant stars. When those stars explode as supernovas, their carbon is scattered into space along with other, heavier elements. Thus all the carbon that astronomers can see on the surface of our sun and other nearby stars today is believed to have come from earlier generations of stars; when they died, they enriched the clouds of gas and dust from which the present stars were born. If anything, stars younger than the sun should contain more carbon than it does, because the clouds that gave rise to them had longer to be enriched by supernovas. Snow and Witt, however, peg the average stellar carbon concentration at between 175 and 275 carbons for every million atoms of hydrogen; the concentration in the sun is about 355 per million.

Because astronomers have always assumed that our sun and solar system are nondescript galactic citizens, many models of how the galaxy works have been geared toward explaining what we see in our own backyard. But if average stars have from half to three-quarters as much carbon as the sun, astronomers may have to reexamine some basic assumptions. For example, the dimming of starlight as it travels through space has been attributed to scattering by carbon-rich interstellar dust. "The current models appear to require more carbon to do this than we think is available," Snow says. Rather than consisting of microscopic grains of pure carbon—graphite or diamond—as some theorists have suggested, the dust may be a mixture of silicon, oxygen, and hydrogen as well as carbon.

THERE'S A DEARTH of carbon in our galaxy's stars and nebulas.

Tony Hallas/SPL/Photo Researchers

Does a carbon deficit decrease the likelihood of carbon-based life arising elsewhere in the galaxy? Planetary scientist John Lewis of the University of Arizona, an expert on the chemistry of the early solar system, doesn't think so. Our solar system, he points out, has natural mechanisms for forming rich pockets of carbon—they're called comets, and they're carbon-rich because they formed far enough from the sun for carbon to solidify rather than evaporate into space, as it tended to do in Earth's neighborhood. Current models suggest that most of the carbon at Earth's surface and in its biosphere came to the planet in a rain of comets early in its history, not long after it cooled. "Half or more of Earth's carbon was brought in by the largest cometary impactor," Lewis says, "so a single event can change the entire history of a planet." Even carbon-poor star systems, he says, might have comets with relatively high concentrations of carbon. Any planets in such systems could get all the carbon needed for life from a few fortuitous impacts.

All well and good, but how did our star come to be endowed with more carbon than its neighbors? "The sun is rich in iron, oxygen, and a number of other elements besides carbon," Snow says. "You can expect this sort of general enhancement across the board from a supernova." Such an explosion need not evenly distribute a dying star's contents, and our solar system may have formed from a clump of gas especially rich in carbon and oxygen—which just happen to be the stuff of life. Says Snow: "There could have been something very local and specialized that happened here." D

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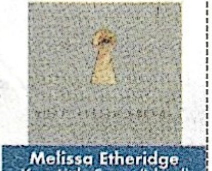

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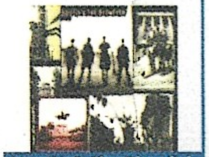
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BIOMECHANICS WATCH

Beetle of Burden

BY CARL ZIMMER

Ounce for ounce, rhinoceros beetles are the world's strongest animals. But just how strong are they? And what makes them so powerful?

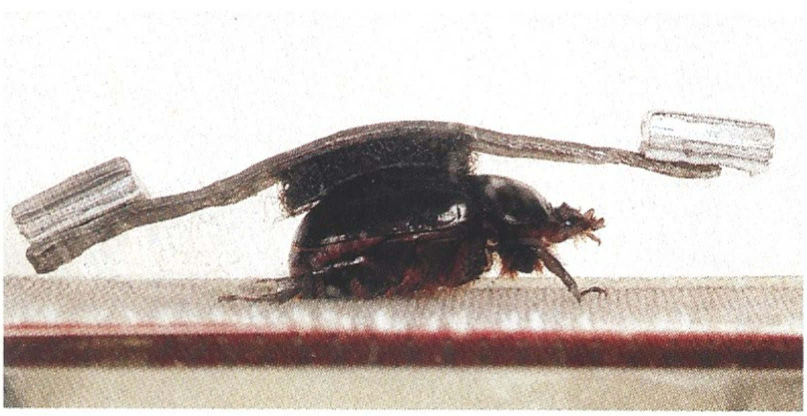
INSPIRATION CAN COME FROM THE strangest places. While perusing the *Guinness Book of World Records*, Rodger Kram saw a startling entry. "They claim that the world's strongest animal is the rhinoceros beetle, and that it can support 850 times its own body weight," he says. Kram, a physiologist at the University of California at Berkeley, decided to test that claim in his lab.

Kram didn't simply stack weights on beetles' backs, since a little tilt would unbalance the load. Instead he created a yoke. He glued a patch of Velcro on each beetle's back and attached to it a thin lead strip that extended over the beetle's head and beyond its rear. On the ends he glued lead weights he had bought from a hobby shop (they're normally used to give model trains traction).

When Kram put the rhinoceros beetles on a treadmill, he discovered that while they were not as strong as the *Guinness Book* claimed, they were still amazing. They could carry up to 100 times their own weight of one-tenth of an ounce, although under that load they could barely move. With 40 times their own weight, they plodded for about ten minutes before becoming exhausted. But with 30 times their own weight, things changed: after half an hour of walking, they still showed no sign of fatigue. "I got bored before they got tired," says Kram.

The beetles' feat is comparable to a 150-pound man walking a mile with a Cadillac on his head without tiring. To a physiologist like Kram, what was particularly mysterious was what fueled the beetles. "In humans and ponies and dogs," he explains, "if you have them carry a weight equal to 10 percent of their body weight, their metabolic rate goes up by 10 percent: 10, 10; 20, 20; and so on in a proportional increase."

For the rhinoceros beetles to follow this rule carrying 30 times their weight, though, they would have to speed up their metabolism by a factor of 30—something only a few creatures on Earth, such as bumblebees, can do. Kram didn't expect ground-dwelling beetles to have a metabolism that could burn at such a high, sustained rate. But he also didn't expect what he found when he sealed his treadmill in a test chamber and measured how much oxygen the beetles consumed, and thus how many calories they burned. While carrying 30 times their weight, the beetles consume only four times more oxygen than when walking unencumbered—an astonishing display of biomechanical efficiency. "If these beetles carry 50 percent of their own weight, it's *absolutely* trivial," says Kram. "They hardly notice it at all."



MYSTERIOUS strength: A rhinoceros beetle hefts a lot of lead.

Rhinoceros beetles don't actually carry heavy loads on their backs in nature, but they do engage in strenuous tasks, such as plowing through forest litter to find food and locking horns with rivals. Kram has yet to figure out their secret. The mechanical tricks of other animals don't apply. Hermit crabs, for example, can carry their heavy shells by dragging their abdomens; with the seafloor supporting most of the load, the crabs just have to move it forward. But rhinoceros beetles keep their bellies high. People practiced at carrying heavy loads on their heads conserve energy by turning some of the energy of their forward movement into the rise and fall of their stride. The beetles, on the other hand, walk too slowly to do anything of the sort. When carrying a load, they don't change their walking style at all.

Kram plans to explore their skeleton and muscles to get to the bottom of this mystery. Like all insects, the beetles have a stiff exoskeleton, and it's possible that it is so exceptionally strong that it can bear the beetle's load without requiring much work from the muscles. But Kram suspects he'll find the solution in the muscles—and he sees the beetles' slowness as a clue. Muscles that contract and relax slowly, he says, can be powerful and metabolically efficient at the same time; the ones that clams use to keep their shells shut tight are an example. Rhino beetles may have muscles like that.

Uncovering their full story could be a great help to researchers trying to build many-legged robots for tasks like mining the moon. After all, a robot with legs of hollow steel is essentially a mechanical beetle. "The people who make robots haven't been too concerned with energy consumption. They just plug the robot in, and there's a nuclear reactor at the other end, and they have plenty of power," says Kram. "But when we really start to make a practical, autonomous, payload-carrying robot, energy conservation will become much more important." D

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EVOLUTION WATCH

We Are All Panamanians

BY KATHY A. SVITIL

When the Isthmus of Panama rose from the sea, it may have changed the climate of Africa—and encouraged the evolution of humans.

THE EMERGENCE OF THE Isthmus of Panama has been credited with many milestones in Earth's history. When it rose from the sea some 3 million years ago, the isthmus provided a bridge for the migration of animals between North and South America, forever changing the fauna of both continents. It also blocked a current that once flowed west from Africa to Asia, diverting it northward to strengthen the Gulf Stream. Now Steven Stanley, a paleobiologist at Johns Hopkins, says that that change in currents may be behind yet another major event: the evolution of humans. When the isthmus rearranged the ocean, he says, it triggered a series of ice ages that in turn had a crucial impact on the evolution of hominids in Africa.

Stanley's hypothesis, which he describes in a new book called *Children of the Ice Age*, is based on ideas developed by a number of oceanographers over the past decade, notably Wallace Broecker of the Lamont-Doherty Earth Observatory. Broecker has called attention to the climatological implications of a fundamental difference between the Atlantic and the Pacific: the Atlantic is much saltier. The difference arises in part because of the dry trade winds that blow west off the Sahara Desert, evaporating water off the ocean and leaving salt behind. "The trade winds are thirsty, and they pick up a lot of moisture from the Atlantic," says Stanley. "Much of that moisture is carried over into the Pacific and drops into the ocean. So the salinity is quite low on the Pacific side of the Isthmus of Panama, but very high on the Atlantic side."

The result is a global system of ocean currents called the conveyor belt. As salty water moves north in the Atlantic—carried by the Gulf Stream, for instance—it gets colder. The combination of extra saltiness and cold temperatures makes the water especially dense—and especially prone to sinking. In the vicinity of Iceland the salty water sinks to the ocean floor. From there it spreads southward to Antarctica, converges with another sinking current, and loops through the Indian Ocean and into the Pacific. There the water wells back up to the surface and slowly returns to the Atlantic around the tips of South America and Africa.

The entire conveyor belt, the theory goes, is driven by the sinking of water in the Atlantic, and ultimately by the salinity difference between the Atlantic and the Pacific. ("The water of the North Pacific gets just as cold as the Atlantic in winter," Stanley says, "but it doesn't sink, because the Pacific is less salty, and therefore more buoyant.") And before the Isthmus of Panama formed, Stanley argues, the conveyor belt didn't exist. Atlantic water flowed directly into the Pacific between the Americas, reducing the salinity difference. The water that then flowed into the North Atlantic, however, wasn't salty enough to sink into the deep ocean; instead it continued northward to the Arctic. Therein lies the key, in Stanley's view, to how the isthmus may have affected human evolution.

***PARANTHROPUS* out, *Homo erectus* in: Did climate do the trick?**

John Reader/SPL/Photo Researchers

As long as North Atlantic waters flowed into the Arctic, he says, they kept it relatively warm—warm enough, for instance, that marine species from temperate climes, like the blue mussel, could use the Arctic to migrate from the Pacific to the Atlantic. After the isthmus formed, however, the conveyor belt denied the Arctic those warm waters, "and because the sun strikes at such a low angle up there," Stanley says, "it got very cold." Pack ice soon formed, which reflected the sun's rays, chilling the region still further. Soon the influence of the frigid north spread inexorably south, as did the glaciers, and the Ice Age began—a long period of waxing and waning ice sheets from which we have yet to emerge.

The impact of the Ice Age was most strongly felt in the higher latitudes, but it also made Africa colder, windier, and drier. Many researchers have suspected that these changes spurred the evolution of *Australopithecus*, the earliest hominid. As Africa cooled and dried, this school of thought contends, the habitat of *Australopithecus* changed. "Before the Ice

Age began, there was probably a very broad zone of open forests on the fringe of the rain forest that was accessible to *Australopithecus*," Stanley says. When the world cooled off, however, the rain forest shrank, while desert and grassland regions expanded. That's a big problem if you're an australopithecine living a semiarboreal life in a forest habitat. "It must have been a tremendous crisis," Stanley says. *Australopithecus* had to survive on the ground and evolve mechanisms that would allow it to do so. Sometime after 3 million years ago, it branched into two lineages—strong-jawed *Paranthropus* and big-brained *Homo*.

> The sediments show the effect twice more in African history—each coinciding with milestones in human evolution.

As it happens, there is now strong evidence linking that evolutionary split to a climate change in Africa. The evidence was reported last year by paleoclimatologist Peter deMenocal of Lamont-Doherty, who studied marine sediment cores drilled off the African coast. The cores contain dust blown off the neighboring continent, so they provide a record of how dry it was there when each layer of sediment was laid down—a colder, drier climate made for more dust. Over the past few million years, the African climate has oscillated continually between periods that were relatively cold and dry and ones that were warmer and wetter. But around 2.8 million years ago, the sediment cores show a pronounced change. The duration of the cold-warm cycles increased, from an average of around 23,000 years to 41,000 years. And judging from the increased amount of dust in the sediment, the cold periods got markedly colder and drier.

What's more, says deMenocal, the sediment cores show the same chilling effect two more times in African history—and each time coinciding with a milestone in human evolution. The next change happened 1.7 million years ago—just about when *Homo erectus*, a direct ancestor of humans, appeared. "The colds got colder, the winds got windier, and the dries got drier," says deMenocal. "And then 1 million years ago the duration of these events became longer again—100,000 years instead of 41,000 years—while the colds got colder still, and the dries even drier." At around that time *Paranthropus*, presumably unable to survive a more hostile environment, died out, leaving the field to *Homo erectus*.

The lengths of the individual cold-warm cycles in Africa reflect the influence on Earth's climate of another factor besides the oceanic conveyor belt—the periodic changes in the orientations of Earth's axis that are known as Milankovitch cycles. The axis wobbles like a top's, tracing out a circle against the stars every 23,000 years; meanwhile the angle at which it is tilted from the vertical oscillates every 41,000 years, from 21.5 degrees to 24.5 degrees and back. (Right now it is 23.5 degrees.)

DeMenocal's sediment cores suggest that 2.8 million years ago, the tilt cycle took over dominance of the African climate from the wobble cycle—and made the climate more extreme. When the tilt angle is low, less sunlight hits the high latitudes of the Northern Hemisphere in summer, less ice melts, and ice sheets expand. That is just what Stanley says happened when the Isthmus of Panama formed and ocean currents stopped warming the Arctic.

The rise of the isthmus, says Stanley, may have made Earth more susceptible to the tilt cycle and may have conspired with it to allow ice sheets to spread over the Northern Hemisphere. The effects of those ice sheets were soon felt in Africa. "It's a jolting notion of how the human genus evolved," Stanley says. "The uplift of this skinny little neck of land between the Americas set in motion an enormous oceanographic change that allowed the Arctic to cool; that had an enormous effect in Africa, by drying the climate and leading to the evolution of *Homo*. In other words, we would not exist if this little neck of land had not risen up across the ocean from where our ancestors lived." D

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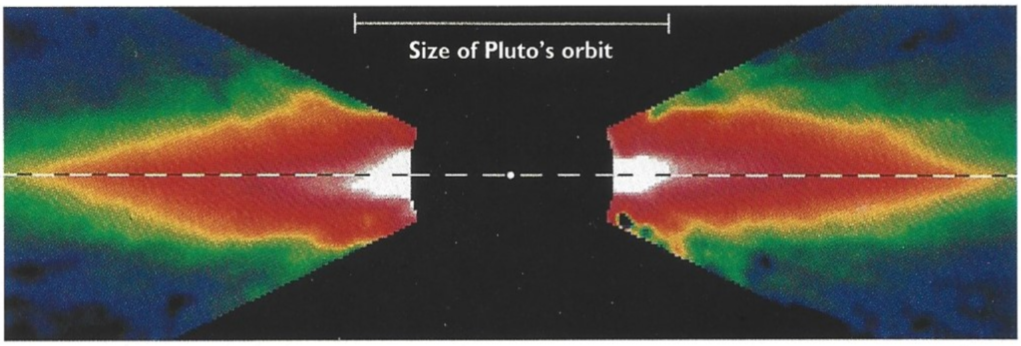
Planets, Planets, Everywhere

BY JEFFREY WINTERS

. . . and maybe even a drop to drink on some of them. The first planets discovered around other stars, though, don't much resemble Earth.

ONLY A YEAR AGO astronomers were wondering when they would ever find planets around other stars. Now planets seem to be popping up everywhere. Last October came the discovery of one around the star 51 Pegasi, 57 light-years from Earth. And at a recent astronomy conference in San Antonio three more stars were reported to have planets. San Francisco State University astronomer Geoff Marcy was in on two of those finds. "We are at the gateway of a new era of science," he told the throng and the television cameras in San Antonio. Marcy had reason to be excited: whereas 51 Peg's planet probably has a climate like a blast furnace, both of Marcy's planets are far enough from their stars that their surfaces could conceivably bear liquid water—the prerequisite, as far as we know, for life.



BETA PIC'S inner dust disk (pink-white) may be tilted by a planet.

Nobody has seen any extrasolar oceans yet. Like the planet at 51 Peg, the new planets are lost in the glare of the stars they orbit. Marcy and Paul Butler of the University of California at Berkeley used a highly sensitive spectrometer to look for the gravitational influence a planet would have on a star. Just as stretching and compressing an accordion changes the distance between its pleats, the motion of a star pulled slightly toward and away from Earth by an orbiting planet can squeeze and stretch the light waves it emits.

For years now Marcy and Butler have been collecting such data, laboring without occasion for televised announcements. They had always expected the search to take a long time. For them to detect a planet, it would have to be at least the size of Jupiter, and they and other astronomers didn't expect such a behemoth to be much closer to its star than Jupiter is to the sun. Jupiter takes nearly 12 years to orbit the sun, so to see a Jupiter pull a star back and forth you would have to watch for at least six years and probably even longer—or so it was widely assumed.

The planet at 51 Peg shattered that assumption. It is Jupiter-size but so close to 51 Peg that its orbit takes just four days. The wobble it produces in the star is huge; Marcy and Butler were able to confirm it by observing 51 Peg for a long weekend last fall. They knew then that it was time to start combing their own large data set in earnest.

By December they had their discoveries. At 47 Ursae Majoris, a star 42 light-years away in the Big Dipper, they found a planet three and a half times Jupiter's size—yet orbiting its star at only twice Earth's distance from the sun. The new planet at 70 Virginis, 60 light-years away in Virgo, could hold eight Jupiters. Yet it lies less than half the Earth-sun distance from its star.

Judging from their size, both planets may be gas giants like Jupiter, but from their orbits, both could support liquid water, like Earth. Marcy calls the planet at 70 Virginis Goldilocks; with an estimated temperature of 185° F, it is neither too cold nor too hot—and not just for water. "This temperature is not too warm to prohibit the existence of complex molecules—perhaps organic molecules—on the surface or in the atmosphere of the planet," he says. Of course, he is speculating. It will be years before astronomers answer such questions.

Meanwhile another giant may be lurking in a dusty disk surrounding the star Beta Pictoris, 50 light-years away. A Hubble telescope image made by Chris Burrows of the Space Telescope Science Institute and his colleagues shows that the inner disk is slightly tilted with respect to the outer disk—perhaps because the dust is being pulled by a planet. A planet of Jupiter's mass and orbit, Burrows calculates, might do the trick.

If so, that would make Beta Pictoris the only new planetary system remotely like our own; the others all have giant planets in the wrong places. But astronomers still haven't found enough specimens to know what a "normal" planetary system looks like. "Right now this is stamp collecting," Butler says. "We find a planet—great! But where does it fit in the greater scheme of things?"

By the decade's end he may know, when several teams using the world's largest telescopes will have surveyed 1,000 stars. And in San Antonio, NASA administrator Daniel Goldin announced that the space agency was making the search for Earth-like planets (as opposed to Jupiter-like ones) a priority. "In ten years or so," he says, "we should have the technology to identify planets like our own and determine if they have life." D

Chris Burrows, STScI, ESA, J. Krist (STScI), the WFPC2 IDT team, and NASA

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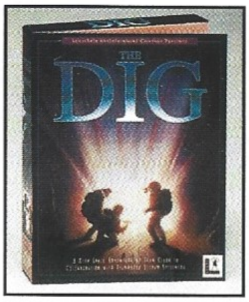

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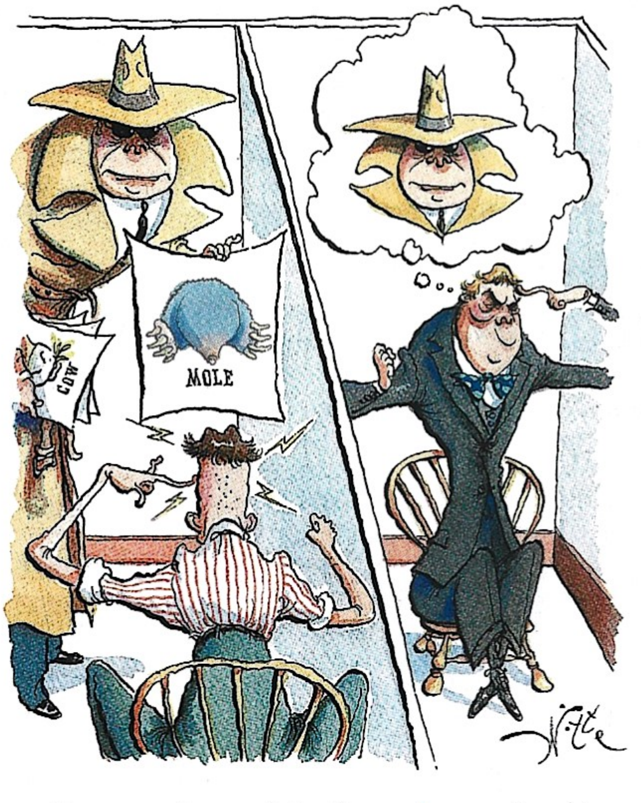
CIA ESP

BY JEFFREY KLUGER

IS IT JUST ME, OR DOES ANYONE ELSE MISS THE OLD SOVIET Union? As far as I'm concerned, if you were looking for a first-rate, grade A, good-time war, you just couldn't beat the cold war. ■ There were a lot of things that made the cold war a special time in world history, but the most important was probably the historic figures involved. Americans, weary of the past decade's global conflicts, chose as their leader in 1952 the reassuringly low-key Dwight Eisenhower. The former general was so wildly popular that Americans took to showing their support for him by sporting campaign buttons that read simply I LIKE IKE—a far less complicated sentiment than would be exhibited in the far more analytical 1990s (I *THINK* I LIKE IKE; I'M NOT SURE I'M READY TO MAKE A COMMITMENT TO IKE; I'M IN A CODEPENDENT RELATIONSHIP WITH IKE). The Soviet Union was equally passionate about its leaders, choosing as its premier the charismatic Nikita Khrushchev. A stirring political orator, Khrushchev was perhaps best known for removing his shoe and banging it on his desk at the United Nations, thus instantly easing world tensions by replacing the long-feared jackboot of fascism with the lace-up wing tip of communism.



Just as dramatic as the people of the era was the language of the era. It was during the cold war that America saw the emergence of McCarthyism, a bold political movement in which courageous government investigators fought to keep the country safe from Zero Mostel, Burl Ives, and Gypsy Rose Lee. It was during the cold war too that Vice President Richard Nixon faced off against Khrushchev in the now-legendary "kitchen debate," besting the Soviet leader with the memorable declaration, "I am not a cook!" Most important, it was during the cold war that the nation first started to worry about its various—and ominous—"gaps."

Extrasensory perception requires a lot of intelligence—*central* intelligence.

Unlike the Gaps of the 1990s, which concern themselves less with geopolitics and national security than with Stone Washed Denims® and Relaxed Fit Khakis®, the gaps of the 1950s were of a far more Serious Nature®. For the better part of a generation, concerned Americans listened to dark warnings of missile gaps, preparedness gaps, and troop gaps. Now, according to newly declassified documents, it seems the American intelligence community was also concerned with an entirely different kind of gap: a genuinely feared, utterly in earnest "psychic gap." Over the last 20 years of the cold war, the United States, it was revealed last year, spent $20 million investigating extrasensory perception and other "psychic phenomena" in an effort to determine whether these forces of the paranormal world could somehow be put to use by espionage experts in the natural world.

In a deficit-conscious era in which government officials have contemplated balancing the federal budget with everything but Publisher's Clearinghouse vouchers, the idea of spending good tax money to study psychic awareness certainly seems wasteful, but national security advisers at the time believed they had reasons. Over the years, self-professed clairvoyants had repeatedly been called on by private investigators and local police forces to help investigate all manner of crimes, from kidnappings to bank robberies. If the same extrasensory sleuthing could be used to locate, say, missile bases near Moscow or troop movements in China, the United States

ILLUSTRATIONS BY MICHAEL WITTE

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The Seldane difference

Seldane can give you relief from a range of major allergy symptoms. Even more important, Seldane can give you all that relief while letting you stay alert*—unlike some over-the-counter remedies that may leave you feeling spacey or drowsy. (In clinical studies, Seldane caused no more drowsiness than a placebo [sugar pill].)

Who should not take Seldane

Seldane isn't for everyone. There are risks for some people. So read this message thoroughly to find out specifically who should not take Seldane.

WARNING: YOU MUST NOT TAKE SELDANE if you are also taking the prescription antifungal medicines itraconazole (Sporanox®) or ketoconazole (Nizoral®) or the prescription antibiotics erythromycin, clarithromycin (Biaxin®), or troleandomycin (TAO®), or if you have liver disease. DO NOT TAKE MORE THAN the amount prescribed by your doctor. Seldane has been associated with rare occurrences of abnormal heartbeats, heart attack, and death under these conditions. Please see important additional information on an adjacent page.

Due to similarities in the drugs, it is also recommended that the antifungal drugs fluconazole, metronidazole, and miconazole, and the antibiotic azithromycin, not be used with Seldane.

Tell your doctor before taking Seldane if you have any liver or heart problems. Also, while using Seldane, tell your doctor if you ever feel faint, become dizzy, or have any irregular heartbeats.

Do not use Seldane with any other prescription or nonprescription medicine without first talking to your doctor. If you become pregnant or are nursing a baby, talk to your doctor about whether you should take Seldane. Your doctor will decide whether you should take Seldane based on the benefits and risks.

It is always important to tell your doctor about any medicines you are using, including antifungals and antibiotics.

Your doctor knows what is best for you

Because Seldane is a prescription medicine, only your doctor, or other health care professional authorized to prescribe, can decide if you're a candidate for it. Ask if you can join the millions of people who trust their allergies to Seldane. So on the day of your big race, you'll know you did your personal best.

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*In clinical studies involving over 11,000 patients, the reported incidence of drowsiness with Seldane (5.8%) did not differ significantly from placebo (6.9%).

SEE ADDITIONAL IMPORTANT INFORMATION ON AN ADJACENT PAGE.

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Brief Summary of
Prescribing Information as of January 1995
SELDANE®
(terfenadine)
60 mg Tablets

WARNING BOX
QT INTERVAL PROLONGATION/VENTRICULAR ARRHYTHMIA

RARE CASES OF SERIOUS CARDIOVASCULAR ADVERSE EVENTS, INCLUDING DEATH, CARDIAC ARREST, TORSADES DE POINTES, AND OTHER VENTRICULAR ARRHYTHMIAS, HAVE BEEN OBSERVED IN THE FOLLOWING CLINICAL SETTINGS, FREQUENTLY IN ASSOCIATION WITH INCREASED TERFENADINE LEVELS WHICH LEAD TO ELECTROCARDIOGRAPHIC QT PROLONGATION:

1. **CONCOMITANT ADMINISTRATION OF KETOCONAZOLE (NIZORAL) OR ITRACONAZOLE (SPORANOX)**
2. **OVERDOSE, INCLUDING SINGLE DOSES AS LOW AS 360 MG**
3. **CONCOMITANT ADMINISTRATION OF CLARITHROMYCIN, ERYTHROMYCIN, OR TROLEANDOMYCIN**
4. **SIGNIFICANT HEPATIC DYSFUNCTION**

TERFENADINE IS CONTRAINDICATED IN PATIENTS TAKING KETOCONAZOLE, ITRACONAZOLE, ERYTHROMYCIN, CLARITHROMYCIN, OR TROLEANDOMYCIN, AND IN PATIENTS WITH SIGNIFICANT HEPATIC DYSFUNCTION.

DO NOT EXCEED RECOMMENDED DOSE.

IN SOME CASES, SEVERE ARRHYTHMIAS HAVE BEEN PRECEDED BY EPISODES OF SYNCOPE. SYNCOPE IN PATIENTS RECEIVING TERFENADINE SHOULD LEAD TO DISCONTINUATION OF TREATMENT AND FULL EVALUATION OF POTENTIAL ARRHYTHMIAS.

(See CONTRAINDICATIONS, WARNINGS, CLINICAL PHARMACOLOGY, AND PRECAUTIONS: DRUG INTERACTIONS.)

DESCRIPTION

SELDANE (terfenadine) is available as tablets for oral administration. Each tablet contains 60 mg terfenadine. Tablets also contain, as inactive ingredients: corn starch, gelatin, lactose, magnesium stearate, and sodium bicarbonate.

INDICATIONS AND USAGE

SELDANE is indicated for the relief of symptoms associated with seasonal allergic rhinitis such as sneezing, rhinorrhea, pruritus, and lacrimation.

Clinical studies conducted to date have not demonstrated effectiveness of terfenadine in the common cold.

CONTRAINDICATIONS

CONCOMITANT ADMINISTRATION OF TERFENADINE WITH KETOCONAZOLE (NIZORAL) OR ITRACONAZOLE (SPORANOX) IS CONTRAINDICATED. TERFENADINE IS ALSO CONTRAINDICATED IN PATIENTS WITH DISEASE STATES OR OTHER CONCOMITANT MEDICATIONS KNOWN TO IMPAIR ITS METABOLISM, INCLUDING SIGNIFICANT HEPATIC DYSFUNCTION, AND CONCURRENT USE OF CLARITHROMYCIN, ERYTHROMYCIN, OR TROLEANDOMYCIN. QT PROLONGATION HAS BEEN DEMONSTRATED IN SOME PATIENTS TAKING TERFENADINE IN THESE SETTINGS, AND RARE CASES OF SERIOUS CARDIOVASCULAR EVENTS, INCLUDING DEATH, CARDIAC ARREST, AND TORSADES DE POINTES, HAVE BEEN REPORTED IN THESE PATIENT POPULATIONS. (See WARNINGS and PRECAUTIONS: Drug Interactions.)

SELDANE is contraindicated in patients with a known hypersensitivity to terfenadine or any of its ingredients.

WARNINGS

Terfenadine undergoes extensive metabolism in the liver by a specific cytochrome P-450 isoenzyme. This metabolic pathway may be impaired in patients with hepatic dysfunction (alcoholic cirrhosis, hepatitis) or who are taking drugs such as ketoconazole, itraconazole, or clarithromycin, erythromycin, or troleandomycin (macrolide antibiotics), or other potent inhibitors of this isoenzyme. Interference with this metabolism can lead to elevated terfenadine plasma levels associated with QT prolongation and increased risk of ventricular tachyarrhythmias (such as torsades de pointes, ventricular tachycardia, and ventricular fibrillation) at the recommended dose. SELDANE is contraindicated for use by patients with these conditions (see WARNING BOX, CONTRAINDICATIONS, and PRECAUTIONS: Drug Interactions).

Other patients who may be at risk for these adverse cardiovascular events include patients who may experience new or increased QT prolongation while receiving certain drugs or having conditions which lead to QT prolongation. These include patients taking certain antiarrhythmics, bepridil, certain psychotropics, probucol, or astemizole; patients with electrolyte abnormalities such as hypokalemia or hypomagnesemia, or taking diuretics with potential for inducing electrolyte abnormalities; and patients with congenital QT syndrome. SELDANE is not recommended for use by patients with these conditions.

The relationship of underlying cardiac disease to the development of ventricular tachyarrhythmias while on SELDANE therapy is unclear; nonetheless, SELDANE should also be used with caution in these patients.

PRECAUTIONS

Information for Patients

Patients taking SELDANE should receive the following information and instructions. Antihistamines are prescribed to reduce allergic symptoms. Patients should be advised to take SELDANE only as needed and NOT TO EXCEED THE PRESCRIBED DOSE. Patients should be questioned about use of any other prescription or over-the-counter medication, and should be cautioned regarding the potential for life-threatening arrhythmias with concurrent use of ketoconazole, itraconazole, clarithromycin, erythromycin, or troleandomycin. Patients should be advised to consult the physician before concurrent use of other medications with terfenadine. Patients should be questioned about pregnancy or lactation before starting SELDANE therapy, since the drug should be used in pregnancy or lactation only if the potential benefit justifies the potential risk to fetus or baby. Patients should also be instructed to store this medication in a tightly closed container in a cool, dry place, away from heat or direct sunlight, and away from children.

Drug Interactions

Ketoconazole

Spontaneous adverse reaction reports of patients taking concomitant ketoconazole with recommended doses of terfenadine demonstrate QT interval prolongation and rare serious cardiac events, e.g. death, cardiac arrest, and ventricular arrhythmia including torsades de pointes. Pharmacokinetic data indicate that ketoconazole markedly inhibits the metabolism of terfenadine, resulting in elevated plasma terfenadine levels. Presence of unchanged terfenadine is associated with statistically significant prolongation of the QT and QTc intervals. **Concomitant administration of ketoconazole and terfenadine is contraindicated** (see CONTRAINDICATIONS, WARNINGS, and ADVERSE REACTIONS).

Itraconazole

Torsades de pointes and elevated parent terfenadine levels have been reported during concomitant use of terfenadine and itraconazole in clinical trials of itraconazole and from foreign post-marketing sources. One death has also been reported from foreign post-marketing sources. **Concomitant administration of itraconazole and terfenadine is contraindicated** (see CONTRAINDICATIONS, WARNINGS, and ADVERSE REACTIONS.)

Due to the chemical similarity of other azole-type antifungal agents (including fluconazole, metronidazole, and miconazole) to ketoconazole and itraconazole, concomitant use of these products with terfenadine is not recommended pending full examination of potential interactions.

Macrolides

Clinical drug interaction studies indicate that erythromycin and clarithromycin can exert an effect on terfenadine metabolism by a mechanism which may be similar to that of ketoconazole, but to a lesser extent. Although erythromycin measurably decreases the clearance of the terfenadine acid metabolite, its influence on terfenadine plasma levels is still under investigation. A few spontaneous accounts of QT interval prolongation with ventricular arrhythmia, including torsades de pointes, have been reported in patients receiving erythromycin or troleandomycin.

Concomitant administration of terfenadine with clarithromycin, erythromycin, or troleandomycin is contraindicated (see CONTRAINDICATIONS, WARNINGS, and ADVERSE REACTIONS). Pending full characterization of potential interactions, concomitant administration of terfenadine with other macrolide antibiotics, including azithromycin, is not recommended. Studies to evaluate the potential interaction of terfenadine with azithromycin are in progress.

Carcinogenesis, Mutagenesis, Impairment of Fertility

Oral doses of terfenadine, corresponding to 63 times the recommended human daily dose, in mice for 18 months or in rats for 24 months, revealed no evidence of tumorigenicity. Microbial and micronucleus test assays with terfenadine have revealed no evidence of mutagenesis.

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Reproduction and fertility studies in rats showed no effects on male or female fertility at oral doses of up to 21 times the human daily dose. At 63 times the human daily dose there was a small but significant reduction in implants and at 125 times the human daily dose reduced implants and increased post-implantation losses were observed, which were judged to be secondary to maternal toxicity.

Pregnancy Category C

There was no evidence of animal teratogenicity. Reproduction studies have been performed in rats at doses 63 times and 125 times the human daily dose and have revealed decreased pup weight gain and survival when terfenadine was administered throughout pregnancy and lactation. There are no adequate and well-controlled studies in pregnant women. SELDANE should be used during pregnancy only if the potential benefit justifies the potential risk to the fetus.

Nonteratogenic Effects

SELDANE is not recommended for nursing women. The drug has caused decreased pup weight gain and survival in rats given doses 63 times and 125 times the human daily dose throughout pregnancy and lactation. Effects on pups exposed to SELDANE only during lactation are not known, and there are no adequate and well-controlled studies in women during lactation.

Pediatric Use

Safety and effectiveness of SELDANE in pediatric patients below the age of 12 years have not been established.

ADVERSE REACTIONS

Cardiovascular Adverse Events

Rare reports of severe cardiovascular adverse effects have been received which include ventricular tachyarrhythmias (torsades de pointes, ventricular tachycardia, ventricular fibrillation, and cardiac arrest), hypotension, palpitations, syncope, and dizziness. Rare reports of deaths resulting from ventricular tachyarrhythmias have been received (see CONTRAINDICATIONS, WARNINGS, and PRECAUTIONS: Drug Interactions). Hypotension, palpitations, syncope, and dizziness could reflect undetected ventricular arrhythmia. IN SOME PATIENTS, DEATH, CARDIAC ARREST, OR TORSADES DE POINTES HAVE BEEN PRECEDED BY EPISODES OF SYNCOPE. (See WARNING BOX.) Rare reports of serious cardiovascular adverse events have been received, some involving QT prolongation and torsades de pointes, in apparently normal individuals without identifiable risk factors; there is not conclusive evidence of a causal relationship of these events with terfenadine. Although in rare cases there was measurable plasma terfenadine, the implications of this finding with respect to the variability of terfenadine metabolism in the normal population cannot be assessed without further study. In controlled clinical trials in otherwise normal patients with rhinitis, small increases in QTc interval were observed at doses of 60 mg b.i.d. In studies at 300 mg b.i.d. a mean increase in QTc of 10% (range –4% to +30%) (mean increase of 46 msec) was observed.

General Adverse Events

Experience from clinical studies, including both controlled and uncontrolled studies involving more than 2,400 patients who received SELDANE, provides information on adverse experience incidence for periods of a few days up to six months. The usual dose in these studies was 60 mg twice daily, but in a small number of patients, the dose was as low as 20 mg twice a day, or as high as 600 mg daily.

In controlled clinical studies using the recommended dose of 60 mg b.i.d., the incidence of reported adverse effects in patients receiving SELDANE was similar to that reported in patients receiving placebo. (See Table below.)

Adverse Events Reported in Clinical Trials

	Percent of Patients Reporting				
	Controlled Studies*			All Clinical Studies**	
Adverse Event	SELDANE n=781	Placebo n=665	Control n=626***	SELDANE n=2462	Placebo n=1478
Central Nervous System					
Drowsiness	9.0	8.1	18.1	8.5	8.2
Headache	6.3	7.4	3.8	15.8	11.2
Fatigue	2.9	0.9	5.8	4.5	3.0
Dizziness	1.4	1.1	1.0	1.5	1.2
Nervousness	0.9	0.2	0.6	1.7	1.0
Weakness	0.9	0.6	0.2	0.6	0.5
Appetite Increase	0.6	0.0	0.0	0.5	0.0
Gastrointestinal System					
Gastrointestinal Distress (Abdominal distress, Nausea, Vomiting, Change in bowel habits)	4.6	3.0	2.7	7.6	5.4
Eye, Ear, Nose, and Throat					
Dry Mouth/Nose/Throat	2.3	1.8	3.5	4.8	3.1
Cough	0.9	0.2	0.5	2.5	1.7
Sore Throat	0.5	0.3	0.5	3.2	1.6
Epistaxis	0.0	0.8	0.2	0.7	0.4
Skin					
Eruption (including rash and urticaria) or itching	1.0	1.7	1.4	1.6	2.0

* Duration of treatment in "CONTROLLED STUDIES" was usually 7-14 days.
** Duration of treatment in "ALL CLINICAL STUDIES" was up to 6 months.
*** CONTROL DRUGS: Chlorpheniramine (291 patients), d-Chlorpheniramine (189 patients), Clemastine (146 patients)

In addition to the more frequent side effects reported in clinical trials (see Table), adverse effects have been reported at a lower incidence in clinical trials and/or spontaneously during marketing of SELDANE that warrant listing as possibly associated with drug administration. These include: alopecia (hair loss or thinning), anaphylaxis, angioedema, bronchospasm, confusion, depression, galactorrhea, insomnia, menstrual disorders (including dysmenorrhea), musculoskeletal symptoms, nightmares, paresthesia, photosensitivity, rapid flare of psoriasis, seizures, sinus tachycardia, sweating, thrombocytopenia, tremor, urinary frequency, and visual disturbances.

In clinical trials, several instances of mild, or in one case, moderate transaminase elevations were seen in patients receiving SELDANE. Mild elevations were also seen in placebo treated patients. Marketing experiences include isolated reports of jaundice, cholestatic hepatitis, and hepatitis. In most cases available information is incomplete.

OVERDOSAGE

Information concerning possible overdosage and its treatment appears in the full prescribing information.

DOSAGE AND ADMINISTRATION

One tablet (60 mg) twice daily for adults and pediatric patients 12 years and older.

USE OF DOSES IN EXCESS OF 60 MG B.I.D. IS NOT RECOMMENDED BECAUSE OF THE INCREASED POTENTIAL FOR QT INTERVAL PROLONGATION AND ADVERSE CARDIAC EVENTS. (See WARNING BOX.) USE OF TERFENADINE IN PATIENTS WITH SIGNIFICANT HEPATIC DYSFUNCTION AND IN PATIENTS TAKING KETOCONAZOLE, ITRACONAZOLE, CLARITHROMYCIN, ERYTHROMYCIN, OR TROLEANDOMYCIN IS CONTRAINDICATED. (See CONTRAINDICATIONS, WARNINGS, and PRECAUTIONS: Drug Interactions.)

HOW SUPPLIED

NDC 0068-0723-61
60 mg tablets in bottles of 100.
NDC 0068-0723-65
60 mg tablets in bottles of 500.

Tablets are round, white, and debossed "SELDANE". Store tablets at controlled room temperature (59-86°F) (15-30°C). Protect from exposure to temperatures above 104°F (40°C) and moisture.

Prescribing Information as of January 1995

Merrell Dow Pharmaceuticals Inc.
Subsidiary of Marion Merrell Dow Inc.
Kansas City, MO 64114

U.S. Patent 4,254,129.
Other patent applications pending.

selb0195a

0044A6

could gain a nifty advantage in the global intelligence game. Alas, two decades of federally sponsored soothsaying failed to turn up anything even remotely concrete; nevertheless the debate continues, with a handful of stubborn researchers defending the work, and a far larger population of mainstream scientists insisting that most things extrasensory are less matters of perception than deception.

It was in 1973 that the Central Intelligence Agency began looking into the business of psychic phenomena. From the start, there was some question whether this was a good idea. It was the CIA, after all, that just over a decade earlier had mounted the Bay of Pigs® invasion, a lightning-like operation in which teams of agency-trained operatives were dispatched to Cuba to assault the beaches on the south side of the island, splash about for a few minutes, and—assuming they were still alive—sail away. This, it was felt, would immediately induce Fidel Castro to lay down his arms and surrender to American authorities. Inexplicably, it didn't. But the CIA's reputation remained good, and the agency went on to explore the extrasensory.

The studies the CIA sponsored were conducted first at the Stanford Research Institute (SRI) in Menlo Park, California, and later at the nearby, privately owned Science Applications International Corporation. Even before the studies started, CIA scientists knew their work was cut out for them. Most laypeople have at one time or another tested themselves for extrasensory abilities, by guessing what card has been picked from a deck, say, or what number between one and ten another person has chosen. For the CIA, however, which was not likely to be confronted by a Third World despot dropping clues like "I'm thinking of a brush war between Afghanistan and Zambia . . . " the methods would have to be a little subtler.

"The CIA studies were conducted in a number of ways," says Jessica Utts, a statistician at the University of California at Davis who participated in some of the experiments, "but all the research had the same objective: to determine how well volunteers could perform in a sensory experiment in which something besides their usual senses was being studied."

Utts, it must be noted, is not just a statistician but also a parapsychology advocate. The term *parapsychology*, of course, comes from the Greek *para*, for "close to," and *psychology*, for, um, "psychology," which together mean "Isn't it time you got as close to a good psychologist as possible?" But in spite of parapsychology's questionable reputation, Utts insists that it is a real science, and the methods she and the other government researchers used in their psychic phenomena studies superficially appear to support that claim.

Generally, the CIA's ESP work involved selecting either a videotape or a photograph of a person, place, or thing, isolating individual volunteers in another room, and asking them to try to determine what the image was. In some trials a second volunteer was told to look at the image, concentrate, and try to transmit it to the receiver; in others the receivers were on their own. "In all instances," Utts says, "we were trying to discover whether the subjects could determine the correct image with a frequency greater than that which could be attributed to chance."

This question of whether the results of an experiment are caused by the phenomenon being investigated or by simple mathematical randomness is critical and is determined by what is known as the study's statistical significance. To calculate statistical significance, investigators factor together a number of variables, including size of sample group, number of trials per subject, number of possible correct answers per trial, the speed of sound in a semiviscous medium, and Eddie Murray's batting average during the 1983 season (.306 with 111 RBIs, hitting from both sides of the plate), and come up with a single numerical answer. If it's lower than .05—meaning there is a less than 5 percent likelihood that you would see the results if chance alone were responsible—the study is deemed statistically significant; if it's greater than .05, it's not.

For Utts and the other ESP investigators, the overall statistical significance of the CIA's studies seemed impressive. "Over the first 15 years of the 20-year study," she says, "154 separate experiments were conducted consisting of 26,000 trials. During those experiments, subjects correctly identified the target image frequently enough that the statistical significance figure was a mere .00000000000000000001—meaning that you would expect to see those results only once in 10^{20} tries if the outcome was due solely to chance. If you trust your observed results, the studies lead to the conclusion that psychic abilities exist."

But can you trust your observed results? For centuries, traveling hucksters have mystified audiences with displays of telepathic abilities that turned out to be nothing more than psychic snake oil. In the American West, visiting clairvoyants would regularly ride into town and put on public shows in which they appeared to read the thoughts of complete strangers in the audience. Ultimately, sharp-eyed townsfolk began to pick up subtle cues that the volunteers the supposed seer called on weren't strangers at all—when they addressed him as Dad, for example. This generally led to a quick tarring and feathering, and soon most of the available positions for traveling hucksters went unfilled. In the 1990s the possibility of extrasensory chicanery is no less great than in the 1890s, and some researchers believe that's just what was going on in the CIA work.

RUSSIA
MEN
WORKIN

"I find it amazing that anyone would suggest that these studies prove the existence of ESP," says psychologist Ray Hyman of the University of Oregon. "Even if you assume that the findings represent a real statistical departure from chance, that's a long way from saying you've got proof of psychic phenomena."

HYMAN, ONE OF THE PSYCHIC STUDies' most vocal detractors, sees a lot of problems with the government's work, not the least of which is the people helping conduct it. "On one level, I have no problem with Jessica Utts," he says. "She's a competent statistician, but she's also a member of the Parapsychological Association." Parapsychologists, he points out, are in the business of establishing that ESP exists, and there's no way such a prejudice won't color their results.

Utts, not surprisingly, takes issue with this. The studies she analyzed, she insists, were conducted according to the most rigid of scientific methods: the trials were usually double-blind, with neither the experimenter nor the subject knowing what image had been selected; the subjects were unknown to the experimenters before the studies began; and when the experimenters chose volunteers, they sometimes went out of their way to select the least psychically inclined ones possible.

"During one set of trials early in the study," Utts says, "we were looking for Stanford employees who might want to serve as subjects, and we learned that one particularly skeptical man had been telling his colleagues what nonsense our work was. After testing, we decided he'd be perfect for our needs, and as it turned out he was. On one trial, he described seeing a target image that resembled a tree, but one that was almost entirely gray and mushroom-shaped at the top. The image we had selected for him was a videotape of a nuclear explosion."

Other trials struck Utts as equally convincing. In one experiment, the researchers dispatched a subject to drive around a site within 100 miles of the SRI building, while another subject, back at the lab, tried to determine where the car was. Almost immediately, the receiver began describing a landscape of "rolling hills," with a propeller-like structure in the foreground "used to produce energy." At that moment, it was later revealed, the volunteer transmitter had been passing the Rolling Hills Windmill Farm in northern California. In still another trial, the experimenters chose as their target image a top-secret underground intelligence facility in West Virginia. With little apparent trouble, two volunteers began describing the appearance and location of the complex, even identifying some of the code words used on the site.

INTRIGUING AS SUCH ANECDOTAL RESULTS seemed to the CIA, mainstream researchers insist that they are proof of absolutely nothing. Sure, a volunteer successfully identified the Rolling Hills Windmill Farm, but in a state like California, where researchers have tried to produce cheap, sustainable energy from everything but pork chops, is that really such a leap? Sure, two other subjects identified the "top secret" West Virginia intelligence facility, but wasn't this facility operated by the same agency that employed double agent Aldrich Ames for close to 20 years before top government auditors at last noticed that a Jaguar, a $640,000 home, and a summer dacha near Grozny were in fact not included in the agency's retirement package? If that could slip through the agency's cracks, couldn't an address in West Virginia?

"This research was conducted for 20 years," says Hyman, "and the entire time it was considered classified. There is no surer way to call the credibility of your work into question than to conduct it in secret. Suppose there was some flaw in the researchers' methods? Suppose information about the target images was somehow getting to the subjects? It's the most basic of research protocols to provide access to your findings and allow other people to try to replicate your results."

Despite such criticism from the community of mainstream scientists, parapsychologists are unfazed and are already progressing to the next step in their work: determining not just which subjects in the studies are the genuine clairvoyant articles but how they came by their remarkable powers in the first place. For most storefront psychics, the origins of ESP have always been a mystery, the best explanations having something to do with wearing a floral sarong, having a name like Madame Rosa, and accepting most major credit cards. For the CIA studies, the parapsychologists are looking for something a bit more scientific, and Utts believes they may be on track.

"Some researchers believe there is a detector of some kind in the brain that is able to perceive change—change in the visual field, change in the thought field—providing information about people or objects that are otherwise unseen," she says. "Interestingly, we found that the greater the variety within a target image—the greater the number of colors or shapes, for example—the better the volunteers did, suggesting that change was indeed what they were responding to."

Of course, while psychics may be responding to changes in "thought fields," the CIA must respond to changes in the political field. With Washington budget writers keeping an ever-closer eye on the nation's bank account, the CIA recently approached Hyman, as well as Utts, and asked him to evaluate the parapsychology studies to help the agency decide whether to spend its limited funds elsewhere. When an agency with the ability to destabilize foreign regimes, fight clandestine wars, and assemble dossiers on domestic troublemakers asks for a performance review, most people would find it hard to be completely candid ("Great study, guys. Honest. Can I freshen that drink for you?"). Hyman, however, was not reluctant to tell the CIA what he thought.

"Despite 20 years of work," he says, "the parapsychologists were not able to offer a positive theory that explains why psychic phenomena exist." Rather, they came up with a negative one that simply accepts the studies' statistical results and asks what, other than ESP, could account for them. "That's not proof," notes Hyman. "That's argument."

It was not, evidently, an argument that was good enough to persuade the CIA. Shortly after this evaluation, agency officials decided to stop funding the studies. After reflection, it's hard to disagree with them. In a world in which the geopolitical stakes are so high, does the United States really want to be in the position of relying on the likes of Carnac the Magnificent to challenge the likes of Saddam Hussein? ("He guessed my height, weight, *and* date of birth! I *had* to surrender Kuwait.") Could even the most sensitive mystic replace even the least sensitive satellite in pinpointing the location of enemy subs? ("I'm getting a picture of water. . . ") Would State Department negotiators who decided to play the China card have to remember to show it to the audience before placing it back in the deck? Until these questions are answered, the CIA might be well advised to steer clear of the paranormal—lest *government intelligence* start to seem more of a contradiction in terms than ever.

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NIGHT WATCHMAN

Just a Coincidence?

BY BOB BERMAN

EVEN EDUCATED PEOPLE CAN BE SURPRISINGLY reluctant to accept simultaneous events as coincidence. Say lightning strikes the church steeple just as old Aunt Mildred dies. Many will see a mystical connection between the events rather than view them as a weird but statistically plausible chance occurrence. ▪ Coincidences are fun and fascinating, but they make scientists nervous. Case in point: the Andromeda galaxy. This nearest of all spiral galaxies could have had any size at all. In fact, Andromeda is the biggest and brightest within 50 million light-years of Earth. Astronomers, suspicious of what later turned out to be mere coincidence, initially doubted their distance measurements to the galaxy. We want our neighborhood to represent the universe, not be populated by oddballs.

Space, empty as it is, is crammed with coincidences. We gaze into a sky that displays only two disks, sun and moon, that just happen to appear the same size. The sun's rotation and the moon's revolution have nearly the same period of just under a month—coincidentally, of course. In the nineteenth century astronomers were thrown into a tizzy when they found that the planets' distances from the sun (in astronomical units) seemed to follow a numerical sequence generated by taking the progression 0, 3, 6, 12, 24, 48, 96, 192, and 384, adding 4 to each, and then dividing by 10. The "law," however, turned out to have no physical basis; it's just a numerological quirk.

The Granger Collection

Simultaneous cosmic events aren't usually related. But there's always a chance. . . .

More instructive are the *apparent* coincidences, where chance is not involved. Novice astronomers are often amazed that the moon spins on its axis in the same period in which it revolves around Earth, keeping its farside forever hidden from our view. A closer look, however, reveals the noncoincidental explanation: our planet's greater pull on the near side of the moon brakes the moon's rotation and holds it in place like an invisible finger.

Similarly, planetary observers often saw particular dusky markings on Mercury when that planet completed its orbit; it seemed certain that Mercury had an 88-day rotation, in sync with its 88-day revolution around the sun. But radar imaging in the mid-1960s showed a rotation of 59 days, two-thirds of Mercury's 88-day year. How, then, to explain the seemingly annually recurring features?

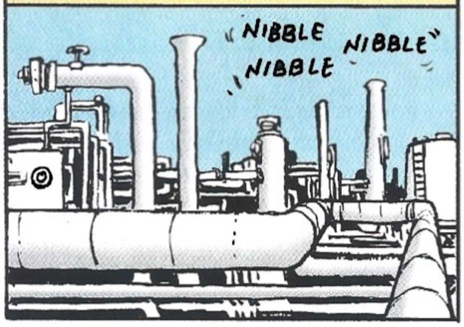
Again, gravitational tugs—only this time from the sun—are to blame. Mercury, like Earth, is not quite round. Instead, it has a slight egg shape, with bulges at either end of the planet. The bulges have a bit more mass than the rest of the planet, and so the sun tugs on them extra hard—harder still when Mercury is at perihelion, the point in its orbit closest to the sun. The tugs slow Mercury's rotation so that one or the other bulge always faces the sun at perihelion. The result is not a synchronous orbit but a stable variation: in every revolution, Mercury rotates one and a half times. To observers, then, markings on the planet reappear every two revolutions—enough to falsely convince them of the features' permanence and of a synchronous rotation that does not exist.

Had enough? Did you know that the number of astronomical units in a light-year (63,240) is virtually the same as the number of inches in a mile (63,360)? Or that the number of seconds in a day (86,400), times 10, is the same as the approximate diameter of the sun (864,000 miles)?

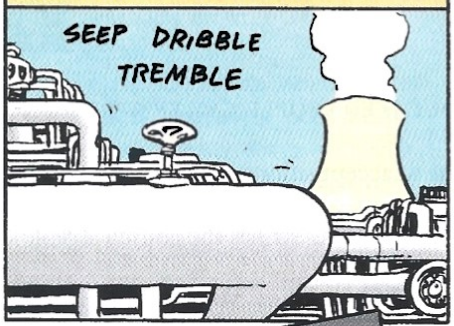
Makes you think, doesn't it? D

BY LARRY GONICK

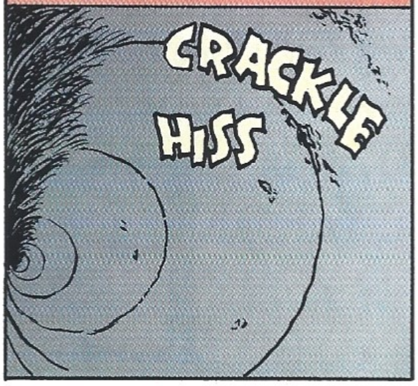
DON'T LOOK NOW... BUT OUR *INFRASTRUCTURE* IS BEING EATEN FROM INSIDE LIKE A TERMITE-INFESTED STUMP...



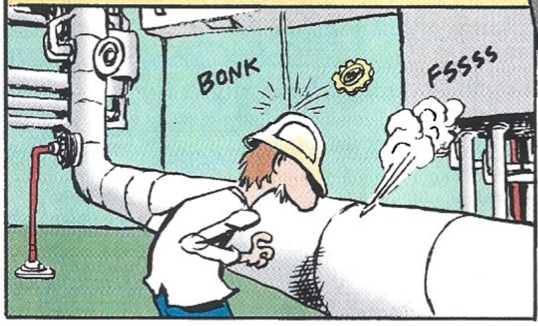
WHEREVER LIQUIDS FLOW IN PIPES, BUBBLE IN CHAMBERS, OR FERMENT IN VATS... IN BREWERIES, BOILERS, NUCLEAR POWER PLANTS...



HIDDEN *PITS* AND *CREVICES* ARE FORMING...



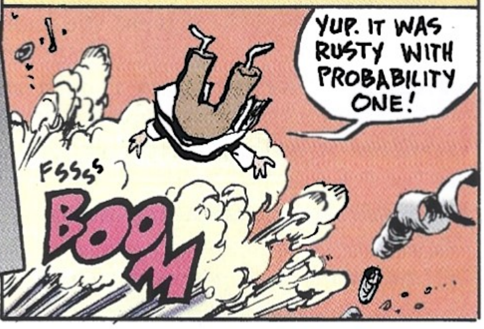
SADLY, CORROSION IS A MURKY, CRYPTIC PROCESS. ENGINEERS KNOW *WHERE* IT'S LIKELY TO HAPPEN, BUT THEY DON'T KNOW *WHEN* OR *HOW FAST*...

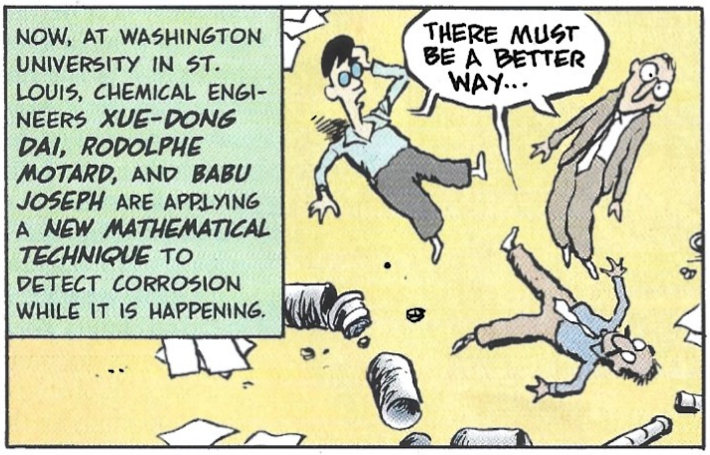


IT'S THE PITS

UGLY OLD PROCESS MEETS SEXY NEW TECHNIQUE

TO SEE CORROSION, YOU EITHER *SHUT DOWN* A SYSTEM AND TAKE IT APART, WHICH COSTS A FORTUNE, OR WAIT FOR A *FAILURE*, WHICH COSTS A FORTUNE.

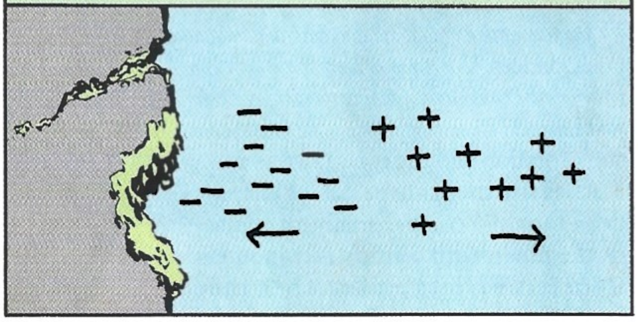

YUP. IT WAS RUSTY WITH PROBABILITY ONE!
FSSSS
BOOM



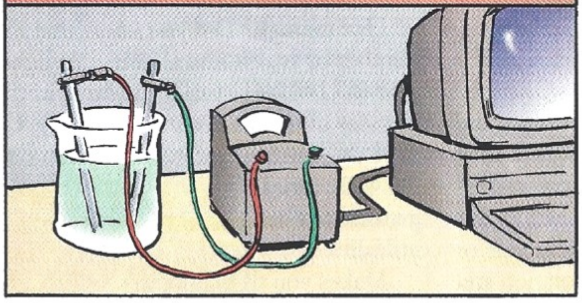
NOW, AT WASHINGTON UNIVERSITY IN ST. LOUIS, CHEMICAL ENGINEERS ***XUE-DONG DAI, RODOLPHE MOTARD,*** AND ***BABU JOSEPH*** ARE APPLYING A ***NEW MATHEMATICAL TECHNIQUE*** TO DETECT CORROSION WHILE IT IS HAPPENING.

THERE MUST BE A BETTER WAY...

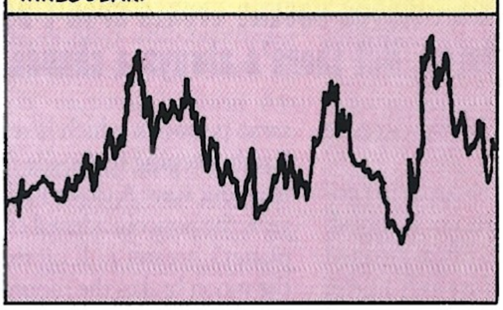
CORROSION IS AN ***ELECTRICAL*** AS WELL AS A CHEMICAL PROCESS. WHEN METAL CORRODES, ***CHARGED PARTICLES*** ARE MOVING AROUND, SIMILAR TO WHAT HAPPENS INSIDE A CAR'S STORAGE BATTERY.



DAI, MOTARD, AND JOSEPH IMMERSED TWO STEEL RODS IN AN **ELECTRICALLY CONDUCTING SOLUTION** OF **SALT WATER** OR **ACID**. THESE WERE WIRED TO **A VOLTMETER** AND **MONITORED BY COMPUTER.**



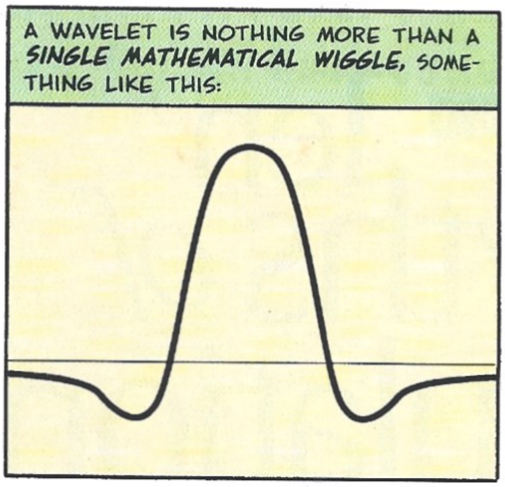
AS CORROSION PROCEEDED, THE COMPUTER RECORDED THE FLUCTUATING VOLTAGE BETWEEN THE RODS—A WILDLY IRREGULAR SIGNAL, SINCE CORROSION ITSELF IS IRREGULAR.



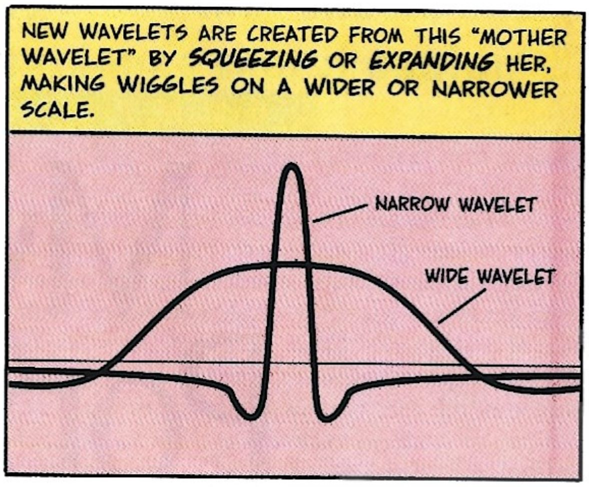
THE QUESTION IS: ARE THERE HIDDEN ***PATTERNS*** IN THE SIGNAL THAT BETRAY MAJOR CORROSION EVENTS, LIKE THE FORMATION OF ***PITS*** AND ***CREVICES?***

THE ENGINEERS TURNED TO THE HOT NEW TECHNIQUE OF

WAVELET ANALYSIS.

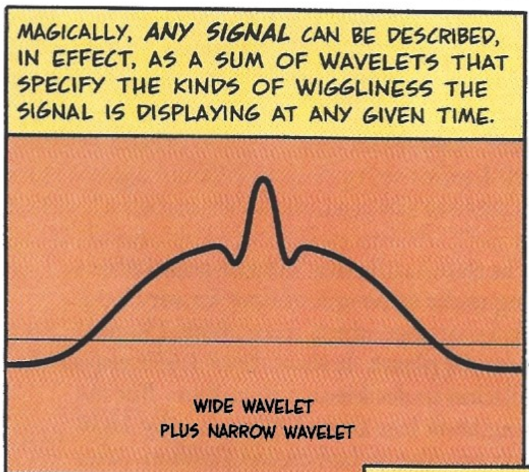


A WAVELET IS NOTHING MORE THAN A ***SINGLE MATHEMATICAL WIGGLE,*** SOMETHING LIKE THIS:



NEW WAVELETS ARE CREATED FROM THIS "MOTHER WAVELET" BY ***SQUEEZING*** OR ***EXPANDING*** HER, MAKING WIGGLES ON A WIDER OR NARROWER SCALE.

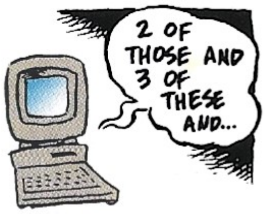
NARROW WAVELET
WIDE WAVELET



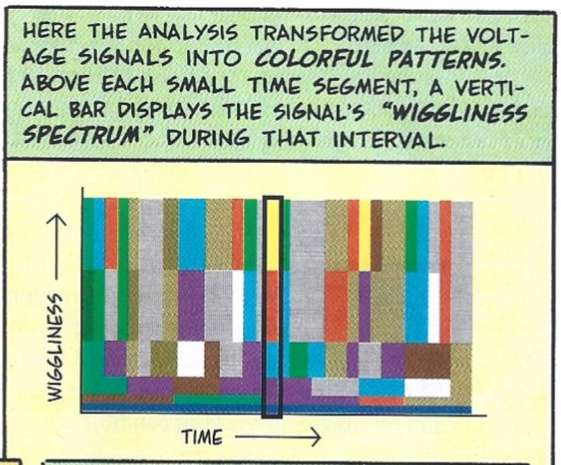
MAGICALLY, ***ANY SIGNAL*** CAN BE DESCRIBED, IN EFFECT, AS A SUM OF WAVELETS THAT SPECIFY THE KINDS OF WIGGLINESS THE SIGNAL IS DISPLAYING AT ANY GIVEN TIME.

WIDE WAVELET PLUS NARROW WAVELET

AN INCOMPREHENSIBLY NOISY GRAPH IS REPLACED BY A FAIRLY SMALL NUMBER OF KNOWN WAVELET CONTRIBUTIONS. IT'S GREAT FOR COMPUTATION!

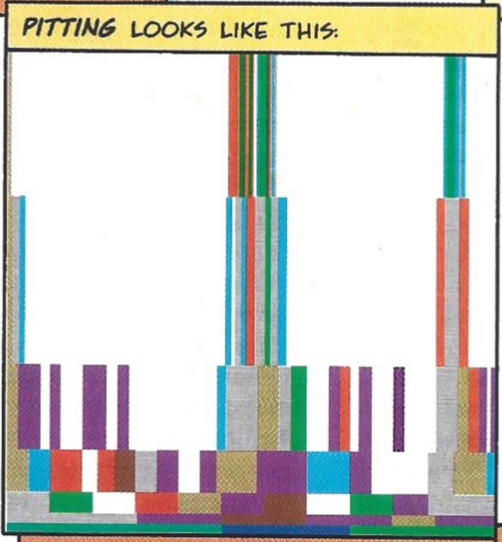


2 OF THOSE AND 3 OF THESE AND...

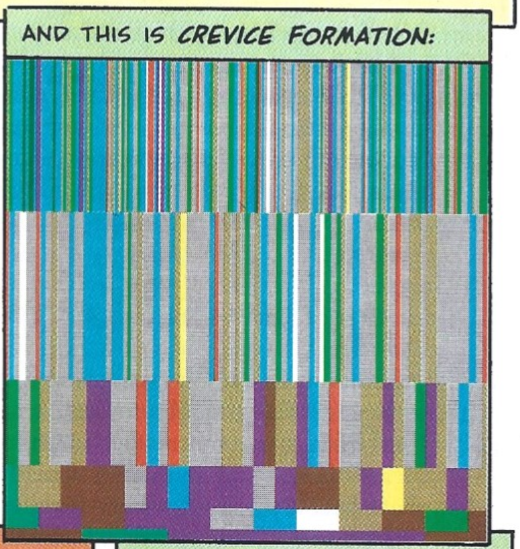


HERE THE ANALYSIS TRANSFORMED THE VOLTAGE SIGNALS INTO ***COLORFUL PATTERNS.*** ABOVE EACH SMALL TIME SEGMENT, A VERTICAL BAR DISPLAYS THE SIGNAL'S ***"WIGGLINESS SPECTRUM"*** DURING THAT INTERVAL.

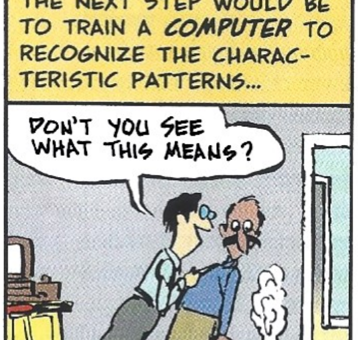
BY EXAMINING THE STEEL RODS UNDER A MICROSCOPE, THE TEAM WAS ABLE TO SHOW THAT ***CERTAIN KINDS OF CORROSION EVENTS GENERATED PARTICULAR PATTERNS.***



PITTING LOOKS LIKE THIS:

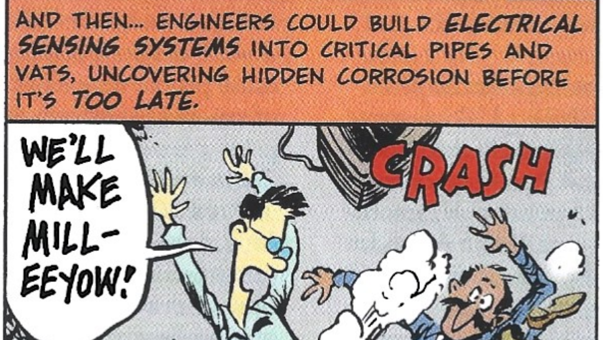


AND THIS IS ***CREVICE FORMATION:***



THE NEXT STEP WOULD BE TO TRAIN A ***COMPUTER*** TO RECOGNIZE THE CHARACTERISTIC PATTERNS...

DON'T YOU SEE WHAT THIS MEANS?
FSSS



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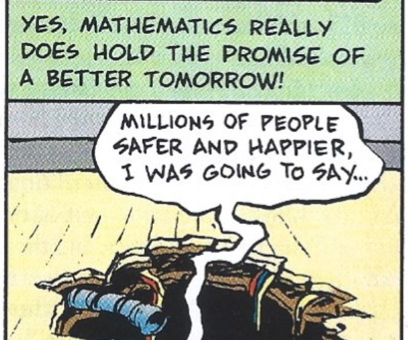


YES, MATHEMATICS REALLY DOES HOLD THE PROMISE OF A BETTER TOMORROW!

MILLIONS OF PEOPLE SAFER AND HAPPIER, I WAS GOING TO SAY...

COMMENTARY

Ten Myths of Population

BY JOEL E. COHEN

FEARS ABOUT EARTH'S BURGEONING human population have long been at the back of many people's minds. Now, it seems, as the threat of nuclear annihilation recedes from the headlines, those fears can move up to claim center stage. Moving along with the anxiety, of course, is a great deal of confusion, not the least of which is about how to recognize a population problem when you see one. Population problems are entangled with economics, the environment, and culture in such complex ways that few people can resist the temptations of unwarranted simplification. The result is a loose and widely accepted collection of myths, all of which wrap a heavy coating of fiction around a nugget of truth. During the 30 years I have spent studying population dynamics, I have become quite familiar with these myths, in all their guises. Here, in their essential form, are ten of the ones that I have encountered most often.

How do we save the world from the burden of too many people? We can start by clearing up a few misconceptions.

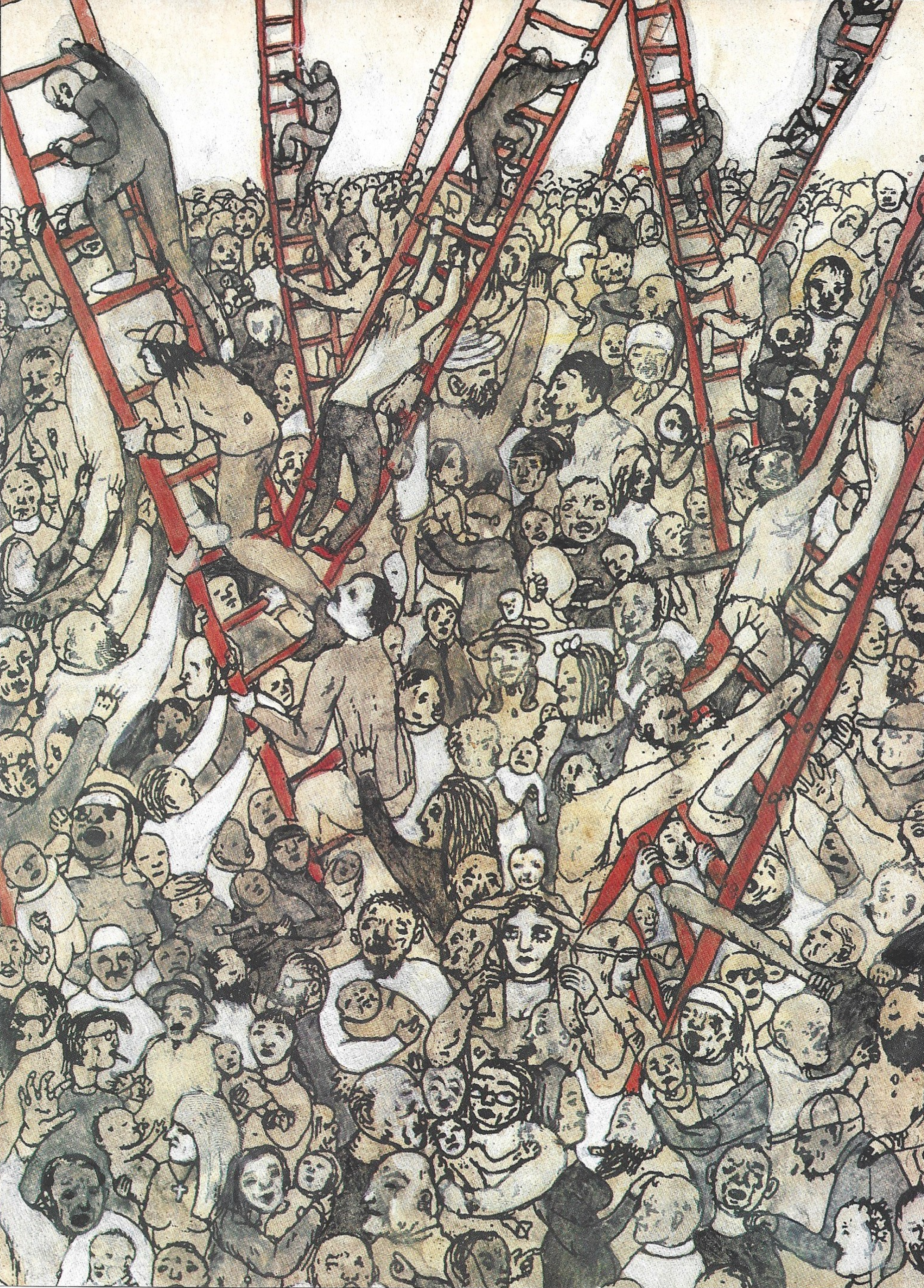
1. The human population grows exponentially.
In 1798 the Reverend Thomas Robert Malthus wrote that any human population, "when unchecked," doubles in a certain unit of time, and then keeps on doubling in the same unit of time. For example, according to his statistics, in "the English North American colonies, now the powerful People of the United States of America, . . . the population was found to double itself in 25 years."

The fact is that hardly any human populations keep doubling in the same unit of time for very long. Two thousand years ago, there were about 250 million people on the planet. It took about 1,650 years for the population to double to 500 million. But the next doubling took less than 200 years—by 1830 Earth's human population had passed 1 billion. After that the doubling time continued to shrink: just another 100 years to reach 2 billion, then only 45 years more to get to 4 billion. Never before the twentieth century had any human being lived through a doubling of Earth's population.

But things have begun to change. In 1965 the global population growth rate peaked at around 2 percent per year (a rate sufficient to double the global population in 35 years, if it were sustained) and then began to fall. It has now dropped to 1.5 percent per year, which yields a doubling time of 46 years. For the first time in human history, the population growth slowed, despite a continuing drop in death rates, because people were having fewer children. The myth of exponential growth misses this human triumph.

2. Scientists know how many people there will be 25, 50, and 100 years from now.
Most demographers no longer believe they can accurately predict the future growth rate, size, composition, or distribution of populations. It's not that demographers are a particularly humble bunch; it's

ILLUSTRATIONS BY JONATHON ROSEN



simply that so many of their past predictions have failed. Researchers could not and cannot predict changes in birthrates or the changes wrought by large migrations of peoples; nor did any of them anticipate that the death rates in poor countries would fall as rapidly as they did after World War II.

Yet demographers can safely predict some things. They know, for example, that everyone who will be at least 18 years old 18 years from now is already born, and that everyone who will be 65 years old or older 20 years from now is at least 45 years old today. This means that if death rates do not change abruptly, demographers can predict with some confidence how many people of working age there will be 18 years from now, and how many potentially retired people 20 years hence.

3. There is a single factor that limits how many people Earth can support.

This myth has a long, distinguished history. In 1679, Antoni van Leeuwenhoek, the inventor of the microscope, estimated how many people the planet could support. He assumed that what limited Earth's population was population density alone—that is, the number of people per unit of land area. He further assumed that Earth could not be more densely inhabited than the Holland of his day, which had an estimated 1 million people at a density of around 300 per square mile. He calculated that Holland then occupied one part in 13,400 of Earth's habitable land. Therefore, he concluded, the planet could support at most 13.4 billion people.

Things turned out to be more complex than Leeuwenhoek imagined. In 1989 a third of the world population lived at densities greater than 300 people per square mile. People, it turns out, can and will live at higher population densities when technologies and environments make it possible, economic incentives and trade make it affordable, and cultural values make it acceptable or even desirable.

Just behind the "standing room" hypothesis in popularity—at least, among those who have not thought much about the problem or the facts—is the belief that what limits global population is the availability of food. In fact, except for people who are actually starving, humans today do not have more or fewer children according to whether they have more or less food. On the contrary, the average number of children per woman is lowest in the rich countries where food is most abundant (such as in Japan and in Europe and North America) and is highest where food availability per person is lowest (as in Africa south of the Sahara).

Since Leeuwenhoek, some 65 estimates of how many people Earth can support have been published, using a wide range of limiting factors—everything from food to land to freshwater, phosphorus, photosynthesis, fuel, nitrogen, waste removal, and human ingenuity. The estimates have ranged from fewer than 1 billion to more than 1 trillion, and in the past few decades they have grown increasingly divergent. But there are a number of problems with all these studies. The advocates of a single limiting factor can rarely determine whether some other factors might intervene before the assumed constraint comes into play. Moreover, even if these determinations were scientifically possible, many of the isolated factors are not independent of one another. True, the amount of available water determines how productive the land will be, but it itself is partially determined by how much energy is available for pumping the water or desalinating it. And that energy capacity depends in part on the amount of water available to flow through hydroelectric dams and to cool nuclear reactors. Everything affects everything else.

Most important, many limiting factors are subject to changing cultural values. If a peasant farmer in Kenya believes that educating her children matters greatly, and if school fees begin to rise, then she may choose to have fewer children not because land is scarce but because she values her children's future more than their labor as farmhands.

4. Earth's population problems can be solved by colonizing outer space.

Let's review the numbers: the world's population of 5.7 billion people is currently growing by roughly 1.5 percent per year. Now, let's say you wanted to use space travel to bring the growth rate down a tiny notch to 1.4 percent. That would require .001 x 5.7 billion = 5.7 million astronauts to blast off in the first year—and increasing numbers in years that followed. Space shuttle launches cost $450 million apiece, so if you ferried ten people to space in each shuttle, the cost per person would be $45 million. Exporting 5.7 million people would cost $257 trillion, roughly ten times the world's annual economic product. Your mass migration would bankrupt the remaining Earthlings, who would still be saddled with a population that doubled every 50 years.

Demographically speaking, space is not the place.

5. Technology can solve any population problem.

People once feared that shipbuilding would be hampered by the scarcity of tall trees for sailing masts, that railroads would be crippled by a shortage of timber for railroad ties, and that the U.S. economy would grind to a halt with the exhaustion of coal. Yet people figured out

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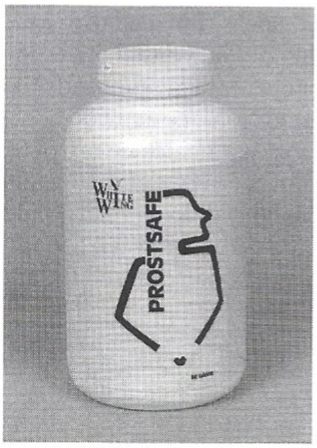

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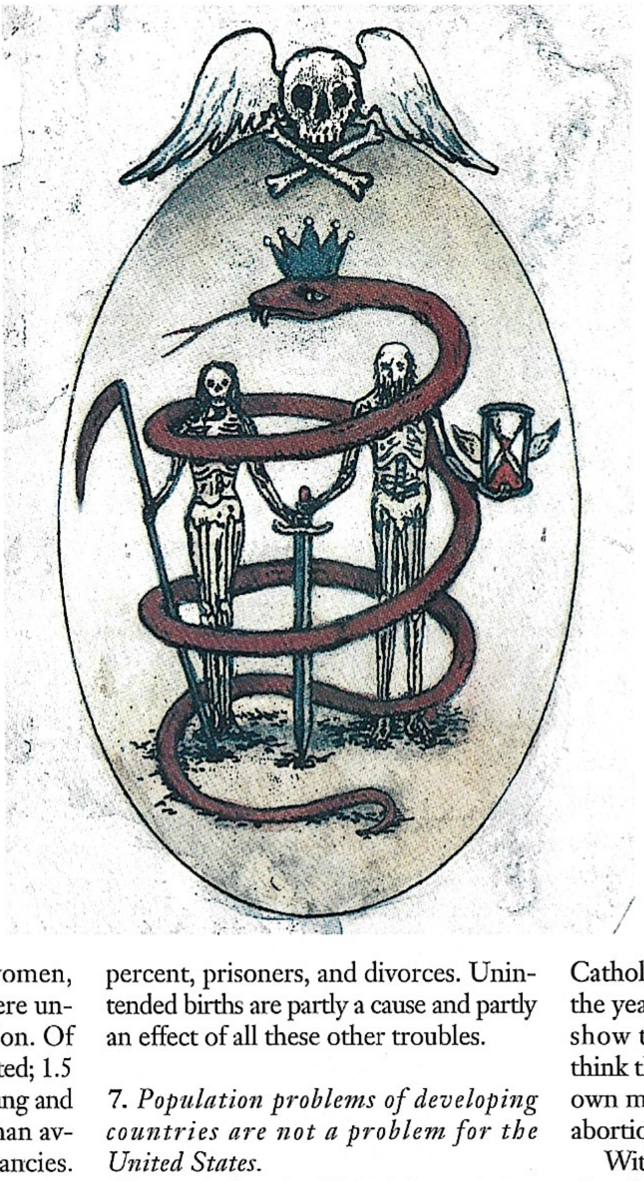
how to switch to metal masts (and then steam power); they invented concrete railroad ties and built superhighways; and they found better ways to extract coal, as well as oil, gas, and other fuels. But these solutions brought new problems, such as acid rain, dramatically rising atmospheric carbon dioxide, stripped lands, and oil spills. Still, technological optimists argue that industrial societies will go on solving problems as they arise.

In technology, as in comedy, timing is everything. For every timely success of technology, doubters can point to problems where solutions did not come in time to avert great human suffering and waste. For example, medical technology's solution for tuberculosis so far is partial at best. One in three humans are infected with tuberculosis (including half the population of Africa), and 3 million of them are dying of it every year. Yet despite decades of medical research, drug-resistant forms of the disease are spreading. Technology will take time to solve such problems—which are ultimately related to population through culture, the environment, and the economy—if it can solve them at all.

6. The United States has no population problem.

When people are born whose parents don't want them, there is definitely a population problem, and the United States suffers this problem in a big way: in 1987, of the 5.4 million pregnancies among American women, about 3.1 million (57 percent) were unintended at the time of conception. Of these, about 1.6 million were aborted; 1.5 million resulted in a live birth. Young and poor women were more likely than average to have unintended pregnancies. In 1987, 82 percent of pregnancies among American teenagers 15 to 19 years old were unintended, as were 61 percent of pregnancies among women 20 to 24 years old. Women with family incomes below the poverty level in 1987 reported that 75 percent of their pregnancies were unintended. The trend is not good: among all U.S. women 15 to 44 years old, the fraction of all births that resulted from intended pregnancies shrank from 64 percent in 1982 to 61 percent in 1988 to 55 percent in 1990.

The inability of the United States to assure that every conception is an intended one is entwined with other social problems. The United States ranks first or second (always behind Australia) among industrial countries in rates of intentional homicides by males, reported rapes of women aged 15 to 59, drug crimes, injuries from road accidents, income disparity between the richest 20 percent of households and the poorest 20 percent, prisoners, and divorces. Unintended births are partly a cause and partly an effect of all these other troubles.



7. Population problems of developing countries are not a problem for the United States.

The myth that the United States is immune to the population problems of the rest of the world ignores migration, infectious diseases, international labor markets, and the shared global commons of crust, oceans, atmosphere, and wildlife. Refugees and immigrants are driven from home by political upheavals, ethnic conflict, poverty, and environmental degradation—all problems that may be exacerbated by rapid population growth—and already play visible roles in the domestic politics of Florida, Texas, and California, as well as in American foreign policy. The health of Americans depends on the health of people outside our borders—infectious diseases do not carry a passport. The rapid population growth of developing countries, leading to fierce wage competition, may even play some role in the movement of jobs out of the United States, although the extent of this role is still controversial because it has not been accurately measured. American workers may do well to recognize their self-interested stake in lowering population growth rates of developing countries.

8. The Roman Catholic Church is responsible for the population explosion.

In some countries church policies have certainly hindered access to contraception and have posed serious obstacles to family planning programs. In practice, however, religion isn't the critical factor for fertility levels among Catholics, not to mention Muslims, Jews, or members of most other religions. Last year Spain and Italy—two Catholic countries—tied with Hong Kong for the lowest levels of fertility in the world, with an average of 1.2 children per woman. In largely Catholic Latin America, fertility has fallen rapidly to the world average of 3.1 children per woman, thanks mainly to modern contraceptive methods. The fertility of American Catholics has gradually converged over the years with that of Protestants. Polls show that nearly four-fifths of them think that couples should make up their own minds about family planning and abortion.

Within the church hierarchy, Catholicism shelters a diversity of views. In 1994, for example, the Italian bishops' conference issued a report stating that falling mortality and improved medical care "have made it unthinkable to sustain indefinitely a birthrate that notably exceeds the level of two children per couple." By promoting literacy for adults, education for children, and the survival of infants in developing countries, the church has helped bring about social conditions that favor a decline in fertility.

9. Plagues, famines, and wars are nature's (or God's) way of solving population problems.

This venerable myth traces back at least to 1600 B.C. According to an ancient Babylonian history, when human commotion disturbed the gods' peace and quiet, the gods inflicted plagues to rid the Earth of humans.

Plagues, of course, are directly caused by viruses, bacteria, and other microorganisms that take advantage of human behavior in a favorable environment. After the last ice age, when sedentary agriculture greatly increased the population density in permanent human settlements, the inhabitants became surrounded by their own wastes and those of their domestic animals and hangers-on like rats and fleas. By the time the Babylonians recorded their creation myths a few thousand years later, people could well have observed that denser settlements were subject to strange new infectious diseases and could have interpreted these diseases as divine interventions. Now we know that humble humans can at least partially control disease. Inexpensive public health measures controlled lethal infectious diseases of childhood in developing countries after World War II, and population growth then accelerated in an unprecedented way.

Modern epidemics, while causing great suffering, have yet to show any probability of putting a brake on population growth. The highly reported Ebola outbreak last year killed 244 people—fewer than are born every minute. As for AIDS, a 1994 United Nations report on the 15 countries in central Africa where it is most prevalent estimated that by 2005 their population growth rate would be 2.88 percent per year in the presence of AIDS. If AIDS were not present, it would be 3.13 percent. These rates correspond to doubling times of 24 years and 22 years, respectively.

Famines today are only partly a result of natural events. Many readers may remember a Pulitzer Prize–winning photograph from 1993, showing a starving Sudanese girl collapsed on a trail, with a vulture looming behind her. At the time, the Sudanese government was just opening parts of its famine-stricken countryside—the scene of a long-running civil war—to relief operations. If aid workers had gotten in sooner, they could have prevented a crop failure from leading to a famine, but the Sudanese government stopped relief from reaching its own people. This is not divine intervention or an act of nature.

Finally, war has not been a major obstacle to human population growth. It's a safe estimate that fewer than 200 million people have been killed in the wars of this century (combined, World Wars I and II may have killed 90 million people, including civilians; since World War II, perhaps 50 million people have lost their lives on conventional battlefields). Yet the population increased from fewer than 1.7 billion in 1900 to 5.7 billion today. This 4-billion-person increase is more than 20 times greater than the number killed by wars.

10. Population is a women's issue, and women are the key to solving it.

If we don't improve the education, welfare, and legal status of women, there is little hope of solving many population problems. Women bear babies, and they are obviously key players in improving the survival of children and lowering fertility. But they are not the only key players. In most of the world, men too need similar help. As demographer Uche Isiugo-Abanihe of the University of Ibadan in Nigeria has pointed out, it is as important to educate African men about the consequences of high fertility as it is African women. In the United States, a 1995 report on unintended pregnancy by the Institute of Medicine concluded that "the prevailing policy and program emphasis on women as the key figures in contraceptive decision-making unjustly and unwisely excludes boys and men." Scientists have discovered it takes two to tango.

Last October a neurophysiologist I was chatting with claimed that the people of India are poorer, more miserable, and more fecund than ever. I quoted him statistics showing that India's average gross national product per person rose 3 percent per year from 1980 to 1993 and that its life expectancy rose from 39 years during the period of 1950 to 1955 to 58 years during the period of 1985 to 1990. I added that in that same period of time the average number of children per woman fell from 6 to 4.1. "Oh, that doesn't matter!" he said. Population myths have a life of their own.

Yet behind the neurophysiologist's exaggerations are valid, urgent concerns. Too many people in India and around the world are far poorer than the means available require them to be. Too many children are born without the prospect of sufficient love, food, health, education, or dignity in living and dying. But only by clearing the myths from our vision of population can we focus on the real problems and find hope without complacency. One way or another, human population growth on Earth must ultimately end. Ending it through voluntary reductions in fertility will make it easier to reduce the poverty of the 4.5 billion people who live on an average of $1,000 a year. At the same time, reducing poverty will make it easier to end population growth through voluntary reductions in fertility. The alternatives are coerced reduction of fertility or the misery of rising death rates. The choice is ours, for now. D

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SHARK THERAPY

SHARKS DON'T GET CANCER, AND IF YOU EAT THEIR CARTILAGE, CLAIM THE ENTREPRENEURS WHO SELL THE STUFF, CANCER WON'T GET YOU. BUT THERE'S NO SOLID EVIDENCE THAT THE TREATMENT WORKS—ONLY THAT SHARKS ARE BEING KILLED AT AN ALARMING RATE.

By Catherine Dold

Photographs by
Max Aguilera-Hellweg

PUNTARENAS, COSTA RICA, IS NO TOURIST haven. Here you won't find people peering through binoculars in hopes of spotting a toucan, or buses carrying visitors to the rain forest. Unlike much of the rest of the country, Puntarenas relies for its fortune not on genteel ecotourism but on the sea. Located on a spit of land jutting into the Gulf of Nicoya and out toward the Pacific, it's a fishing town to its core, complete with bars on every corner, dogs wandering down pockmarked streets, and prostitutes doing their best to entice the men to spend their pay on something other than alcohol.

In a small shop on the main street, businessman Elicinio Briceño Ugalde proudly displays his own take from the sea. A cartoon shark grins from the labels of the blue-and-white bottles lined up on glass-topped counters. "Shark cartilage pills," Briceño Ugalde says, smiling himself. "Come into my office and I'll show you what it's all about." He ducks through a doorway and down a grimy hallway of tiny, padlocked hotel rooms—his other business—and into the bar that doubles as his office. He turns down the jukebox and pops a videocassette into a player. A reporter on the screen begins detailing the new industry that is allowing Briceño Ugalde and many other people in Puntarenas to make a tidy living, at least by Costa Rican standards.

"Shark cartilage," claims the reporter, "can cure cancer."

The reporter, from a Mexican television station, goes on to state that several years ago, scientists at no less an institution than Harvard discovered that shark cartilage could cure up to 80 percent of cancer cases. Looking at X-rays of reportedly cured patients, he declares, "The shark is no longer an animal to be feared." The shark "now gives life."

Taking such reports to heart, Puntarenans like Briceño Ugalde have thrown their money and labor into the shark cartilage business, hauling thousands of the fish from the sea, stripping out the cartilage that makes up their skulls and spines, drying and pulverizing it, and slipping it into gelatin capsules for over-the-counter sale as "food supplements." Briceño Ugalde claims his shark-grinding operation sells 10,000 bottles of pills each month, at about $8.50 for a bottle of sixty 300-milligram pills.

Briceño Ugalde may be exaggerating his sales figures. He and a few others supply only the local market. But a few miles up the Pan American Highway, an armed guard stands sentry at a complex of warehouses, the Corporación Procesadora Cartílago. There thousands upon thousands of sharks are pulverized and readied for pill form. Those pills end up in American health food stores, under the brand name Cartilade, and sell for about $32 for ninety 740-milligram capsules.

Proponents of shark cartilage claim it can cure everything from arthritis to lupus to cancer. Especially cancer. In one of the biggest health fads since laetrile—the apricot-pit-based "cure" for cancer that was all the rage in the 1970s—shark cartilage pills are being snatched up by thousands of cancer patients. The therapy is riding on the coattails of an accepted medical premise: for a tumor to grow, it needs nourishment, so it must induce new blood vessels to grow toward it, in a process called angiogenesis. Theoretically, if that blood supply can be cut off, tumors will wither and die. Shark cartilage, its advocates swear, is anti-angiogenic: it can cut off the blood.

Researchers who conducted the angiogenesis studies being cited as proof for this therapy are furious. Yes, they say, there might well be something in shark cartilage, but it's an awfully big leap from their laboratory studies to a cure for cancer. They find themselves misquoted and used as pawns in what many see as a scam. They fear that such misplaced interest in cartilage will detract from years of legitimate research into angiogenesis, which could indeed someday lead to new treatments for cancer. Environmentalists, too, are upset. Sharks worldwide have taken a beating lately, and this blossoming interest in shark cartilage could mean disaster.

The cartilage craze can be traced back to 1983, when I. William Lane, a nutritionist and biochemist from New Jersey, read a report on angiogenesis. "I saw a paper in *Science*," says Lane, "that said shark cartilage could inhibit new blood vessels and stop the growth of cancer." He got hold of some cartilage, spent three years processing it, and then tried to interest researchers in it. "Everybody laughed at me, but I kept at it," he says. Eventually he convinced scientists at the Institut Jules Bordet in Brussels to take a look. According to Lane, their study showed that when shark cartilage was fed to mice with melanoma, tumors shrank by an average of 40 percent. In 1991, after having no luck in rousing the interest of the National Cancer Institute or other government agencies, Lane took his product to a controversial alternative cancer treatment center in Mexico. Eight terminally ill cancer patients were given daily enemas of a shark cartilage solution. Seven of the eight improved, says Lane, showing a 30 to 100 percent reduction in tumor size.

PUNTARENAN FISHERMEN UNLOAD THEIR CATCH OF SHARKS.

Lane's next clinical trial brought him widespread attention as well as scorn. In 1992 he began working with doctors in Cuba, treating 29 terminally ill cancer patients. "All of them were next to death," he recalls, "but lo and behold, after six weeks they were starting to respond." Today, three and a half years later, he says, 14 of the patients are cancer-free, 9 have died of cancer, and 6 have died of other causes. The results were deemed dramatic enough to be featured on *60 Minutes* in 1993. "From then on," says Lane, "I was famous." Worldwide sales of his book, *Sharks Don't Get Cancer*, took off, and shark cartilage became a $50-million-a-year industry. According to various estimates, some 25,000 to 100,000 people are now using one of dozens of brands of shark cartilage, getting it in health food stores, from infomercials, and over the Internet. At least some of them are buying Benefin, the tins of powdered cartilage Lane's son peddles out of Australia at about $130 a pound.

Lane contends that four proteins in shark cartilage are able to stop the growth of blood vessels. But when asked to explain exactly what these proteins are and how they work, he brushes off questions. "Who cares how it works? What's more important is, *does* it work?" He then launches into a discussion of how cancer research moves too slowly. "I've devoted my time to taking research to the people. When you've got a holocaust, you can't afford to chew your cud. You've got to do something."

Most scientists, of course, care very much about how something works, and for all his impassioned rhetoric, Lane has had little luck convincing them of the value of his theories.

Carl Luer is a senior scientist at Mote Marine Laboratory in Sarasota, Florida, and one whose work Lane often cites. In the mid-1980s, Luer tried to induce tumors in sharks by exposing laboratory fish to carcinogens. No tumors ever formed, as Lane points out in his book. But, says Luer, though sharks tend not to get cancer, their cartilage probably has nothing to do with it. He notes that he also tried to isolate any substance in shark cartilage that prevents blood vessels from developing. "Sometimes you can get active material, sometimes you can't," he says. "But it was clear from our work that whatever this stuff is, it is not involved in keeping the shark healthy. There is no way it is going to be released from the cartilage to go elsewhere in the shark's body."

Could such a substance, if purified from shark cartilage or elsewhere, somehow be used to keep blood vessels from growing in human tumors? Judah Folkman of Harvard Medical School has devoted more than 25 years to that question. In the 1960s he proposed that the growth of a tumor might depend on its ability to trigger new blood vessels and that perhaps tumor growth could be arrested if angiogenesis could be stopped. No one put much stock in his theory at the time, but over the next few years, the pieces fell into place.

In 1971, Folkman reported that he had isolated a factor in

"I'll change my mind if I ever see any study that shows shark cartilage works, but we have solid evidence that it couldn't."

tumors that appeared to make new blood vessels grow. Perhaps if this "tumor angiogenesis factor," as he called it, could be blocked before it kicked in, the tumor could be halted at its initial, harmless size. Knowing that cartilage usually contains no blood vessels, Folkman and his colleagues decided to explore whether cartilage might contain an angiogenesis inhibitor. Using a standard test that measures the growth of capillaries in a chick embryo exposed to various substances, the researchers soon discovered that a bit of cartilage—from a calf—did indeed inhibit capillary growth.

Sharks came into play in the early 1980s, when Folkman's collaborators Anne Lee and Robert Langer at MIT figured the fish might be a good source of cartilage for their studies—a shark's skeleton, after all, is composed *entirely* of cartilage. Lee and Langer implanted pellets of cartilage extract, along with small pieces of tumor, into rabbit eyes. Normally the tumors induce blood vessels to grow toward them from the cornea, but when shark cartilage was present, the scientists found remarkably little capillary growth. They reported their findings in *Science* in 1983, where Lane found them.

Cartilage research has not gone all that much further. In 1990, Langer and his colleagues reported that they had identified a protein in calf cartilage that inhibits angiogenesis. Langer is now trying to isolate the gene for the protein and is still trying to purify the inhibitor in shark cartilage. Japanese researchers also reported in 1990 that they had found another inhibitor in shark cartilage.

A FACTORY WORKER CLEANS TISSUE FROM A SHARK'S JAW AND TEETH.

The study of other ways to interfere with blood vessel growth, meanwhile, has exploded. "We're not sure what yet, but something happens and tumor cells start secreting factors that induce blood vessels to grow," explains James Pluda of the National Cancer Institute. Researchers have already identified 13 of those angiogenic factors, he says, and are trying to pin down the precise function of each in encouraging blood vessel growth. Each defined step is a potential point at which to interfere with the whole process. More than two dozen *anti*-angiogenic factors, none of which came from shark cartilage, have also been identified. Many of them could someday have clinical use, and several are being tested.

Angiogenesis inhibitors might ultimately prove useful against cancer. But, as Folkman says, "it's like going from Kitty Hawk to the moon." None of the inhibitors is yet ready for regular use.

As for shark cartilage pills becoming a cancer treatment, the researchers Lane loves to quote don't believe it will happen. "The shark cartilage extracts that you see advertised—no one has ever seen any evidence that they work," says Langer. "Cartilage did show activity in the rabbit cornea, but that is very different from taking it orally and saying you can stop a tumor." The trials in Mexico and Cuba were not peer-reviewed, notes Folkman, so the results can't be trusted. And the study in Brussels also was not as conclusive as Lane reported. Ghanem Atassi, who conducted it, says a 40 percent reduction in tumor volume was seen in one group of test animals, but only briefly. "There was tumor regrowth in those animals," he says. He and his group "were never able to reproduce those results" and chose not to publish them.

"I'll change my mind if I ever see any study that shows that it works, but we have solid scientific evidence that it couldn't," says Folkman. "In shark cartilage there is also a powerful *stimulator* of blood vessel growth. It would be dangerous to take the stimulator, but the saving grace is that stomach acid destroys both it and the inhibitor. Even if they did somehow survive the stomach acid, proteins are too large to get into the bloodstream intact. That's why you can't drink insulin. And the proteins are present in such tiny quantities that even if they could survive and get in the bloodstream, you would have to eat pounds of it a day to get enough activity."

Shark cartilage's power to defeat cancer, though, is most likely not the chief concern of the people of Puntarenas. With unemployment estimated at 10 percent, they are undoubtedly happy just to find a market for something that was previously considered worthless.

DOWN ON THE DOCKS, THE FISHERMEN of the *Laura*, a 40-foot wooden boat, are unloading their haul from two weeks at sea. While "It's a Small World" plays in the background, one man tosses headless, finless five-foot-long sharks onto the deck from the hold. Another, wearing rubber boots to slosh through the shark guts that soon cover the deck, throws the fish onto the dock. Just above his head is the coil of long-line used to haul in the sharks: 15 miles of line, with a hook every hundred feet. This trip, they got about a ton of sharks. They used to get two to three tons routinely, says the captain.

The headless fish are being sold to William Sancho Campos, one of the owners of the Palmares fish company. More than 20 species of shark pass through his hands, the most common being hammerhead, white-tipped, reef, and basking. Sancho Campos deals only in meat, but he believes that cartilage has played an important role in making the shark an attractive catch. "Because they can sell everything," he says, "fishermen are dedicating themselves to sharks."

The fins and the cartilage-filled heads in the *Laura*'s hold will probably be sold to Guillermo Medrano and his partner, Luis Chen Mok. The fins, which can net as much as $20 per pound, are the most valuable part. Medrano and Mok export about six and a half tons of fins every month, sending most of them to Hong Kong, where they are turned into soup.

Medrano has been dealing in shark cartilage ever since he met Lane many years ago. Lane used to have a hand in the Cartílago factory, Medrano explains, but about a year ago there was a falling-out and Lane sold his interest. Medrano still sells cartilage to the new owners. In his own small factory, he prepares raw shark parts for delivery to Cartílago. Along one wall is a row of large freezers. He opens one, digs through a pile of ice, and pulls out the bloody head of a shark, complete with eyes and gaping, toothy jaws. It's a blue shark, once about five feet long, he estimates. The flesh is sliced off

SHARK SPINAL COLUMNS READY TO BE CLEANED AND PROCESSED.

by young women working at stainless steel tables across the room, he explains, and the jaws and spines are soaked in vats of bleach and water.

The general manager at Cartílago, which supplies Cartilade brand cartilage to the United States, is not quite as forthcoming about his end of the business. Mario A. Lopez Vargas runs his plant from a drab cinder-block office in a compound that looks more like a military installation than a fish factory. The barbed wire fence that surrounds the plant, he says, is to keep people from stealing the payroll. It also marks the "zona franca," a tax-free business zone that the American owners of the plant enjoy. Lopez Vargas declines to reveal just how much cartilage he buys or how it is processed.

"A lot of people think this plant is responsible for the slaughter of sharks," says Lopez Vargas. "But all we are doing is taking advantage of a resource that would be thrown away." The rationale is that sharks will be harvested for their meat and fins anyway. But there is little doubt that shark fishing is increasing as cartilage gains in popularity. Sancho Campos reports that 50 percent more of the fish he buys are sharks than five years ago, even as the fishermen complain that they have to go farther and farther to find them.

Based on Medrano's estimates of how much cartilage he supplies to Cartílago, at least 111,000 large coastal sharks are being crunched into powder at the factory each year. The annual U.S. commercial shark fishery quota for the Atlantic coast, the Gulf of Mexico, and the Caribbean is not much bigger—only about 150,000 large coastal sharks—and many people consider it much too high to be sustainable. "These numbers indicate there is intense fishing pressure in Costa Rica," says Robert Hueter, a senior scientist at Mote Marine Laboratory and the director of the Center for Shark Research. "Without regulations or management, there is an absolute danger that this fishery will collapse very quickly. It can't last more than a couple of years."

The businessmen of Puntarenas profess to believe that sharks reproduce so rapidly that they needn't worry. Nothing could be further from the truth. "Some species need up to 30 years to mature for first reproduction, and some have only one young every other year," says marine scientist Samuel Gruber of the University of Miami. Historically, says Gruber, shark fisheries have been boom-and-bust operations requiring decades to recover. He expects that Costa Rica will be no exception. "They are going to fish out the sharks. That's a fact. You get good catches for a while, then they are gone." In the United States, some shark populations have already declined 70 to 80 percent in the last two decades because of fishing pressure. Shark fin harvesting, which has more than doubled since 1980, has had a major impact on shark fisheries worldwide. Yet there are no international treaties, and few national laws, that protect sharks.

Many Costa Ricans protest that the real problem is the big

CARTILAGE DRIES IN THE MEDRANO FACTORY SUNROOM.

foreign fishing boats from China and Japan and elsewhere that troll their waters, and not the local guys. Some of those foreign "factory ships" have longlines 100 miles long. They never haul in a line; they just keep patrolling it from end to end, picking off fish. One large boat that was docked in Puntarenas could reportedly scoop up more than 70 tons of sharks each time it went to sea.

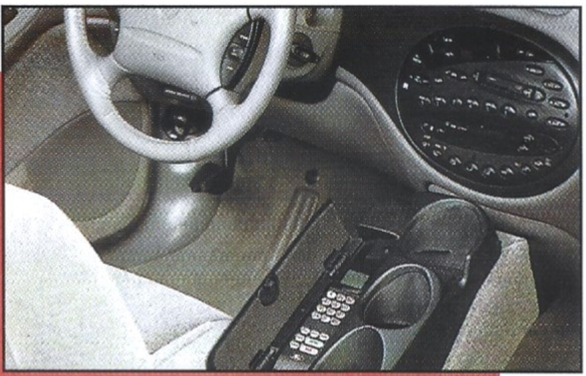
Considering that five years ago few people gave sharks a second thought, environmentalists have made considerable progress pressing for shark fishery controls. In 1994 they persuaded the nations that belong to the Convention on International Trade in Endangered Species (CITES) to call for new data on the biological and trade status of shark fisheries worldwide, and persuaded the World Wildlife Fund to sponsor an international investigation into the trade in shark fins, cartilage, meat, skin, and oil. Eventually, the members of CITES could decide to ban or restrict trade in some of these products, just as they have done for elephant ivory and rhino horns.

The investigation won't be completed until 1997, though, and any trade controls could take several more years to implement, if they happen at all. "We really can't wait until the information comes together before we start managing more effectively," says Merry Camhi, a National Audubon Society ecologist. "We need to be pushing for more management plans and for reductions in existing quotas."

"I can understand the fear of somebody who is told there is nothing more that medicine can do for them, and the lengths they would go to," says Gruber, who was treated for cancer for 13 years. In his own encounter with an alternative treatment, Gruber once ate so many apricot pits that he developed cyanide poisoning. "I consider it a cruel hoax that these people are making money by killing sharks that don't need to be killed and by promising people that they are going to get their cancer cured. I think that is doubly cruel."

In the end, controlled clinical trials will be the only way to prove whether shark cartilage is a miracle cure or a hoax. And in fact, a few researchers are now running FDA-approved clinical trials, usually enrolling only people who have exhausted all other medical options. Stuart Leitner, an oncologist at the Cancer Center at St. Barnabas Medical Center in Livingston, New Jersey, is giving Cartilade to people with breast and prostate cancer. Leitner says he has heard all the objections raised by the medical community, but he is still intrigued. "Instead of saying it doesn't work, let's give it a chance and see what it can do," he says.

Lane has finally gotten involved in a United States–based controlled clinical trial. He is funding a two-year study by José Gonzalez, a urologist at William Beaumont Hospital in Royal Oak, Michigan. Gonzalez will be using Benefin to treat patients with advanced prostate cancer. "The FDA has allowed me to go to the jury," says Lane. "In the next few months I will either be a hero or a dud." D



Ford Technologies Deliver the Comforts of Home

Ford Motor Company has employed various new technologies to create cars with all the comforts and conveniences of a home on wheels — but with no garden to weed or house to paint.

One of the greatest pleasures of driving is hitting the open highway with the windows down and the radio playing loud. But the acoustics of some car stereos are so bad you might not be able to tell Prince from Queen from The Kingsmen at high volume. At our Detroit sound studio, Ford engineers employ the scientific principles of audio design to produce vehicle stereo systems that sound as good as the one in your home — so real you might think that the New York Philharmonic is actually playing in the backseat.

Custom-designed acoustics

To create one particular innovation, engineers replaced ordinary radio circuits with Digital Signal Processing (DSP) equipment, which mathematically calculates and communicates along high-speed computer integrated circuits at 30 million instructions per second. This DSP technology allows you to set your car stereo to re-create the acoustics of a jazz club, concert hall, stadium, church, or newsroom, depending on what you're listening to.

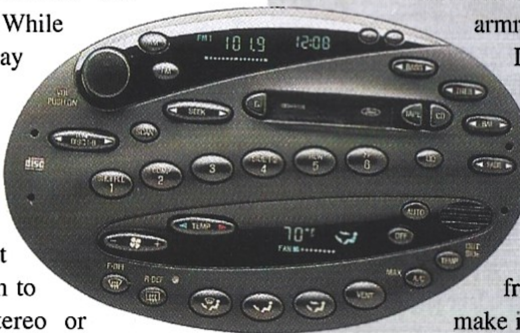
Lux Cassette Radio with DSP

To make our vehicle stereos sound better, each system is acoustically designed specifically for a particular vehicle. And we've triple-sealed vehicle doors in many models, and used interior sound damping materials in key places — which we identified by scanning prototype door skins with laser-holographic interferometry — and even designed the oil pan with a layer of plastic that absorbs engine noise, all to provide a quieter ride. So you can fill the car with the sounds you want to hear. Ford stereo systems are so good we even received patents for the design of the bezels on the control panel.

Integrated control panels

Speaking of control panels, Ford has also used high technology to help reduce the age-old problem of driver discomfort and inconvenience. While driving, you may have experienced the frustration of not being able to see the right control or that fumbling stretch to operate the stereo or turn on the air conditioner or defroster. As you pull into traffic, already late for a meeting, you have to slow down and really concentrate to create a comfortable riding environment. But now Ford's new Integrated Control Panel (ICP) combines the displays and controls for all audio and climate systems into an easy-to-reach, easy-to-understand format.

We've placed the most commonly used controls — such as the radio volume dial — closest to the driver and enlarged the controls for easy identification. Unlike previous systems, the ICP buttons don't act directly on the system; rather they communicate remotely via a multiplex wiring system, thus reducing weight, space, and complexity. Different colors, shapes, and sizes allow you to easily identify and use the controls and displays in 30 percent less time than with traditional systems, while helping you keep your eyes where they should be: on the road, peeled for the next drive-through espresso bar. (This system is currently available on Taurus and Sable).



Taurus/Sable ICP with Electronic Automatic Temperature Control maintains an even interior temperature through the entire vehicle automatically.

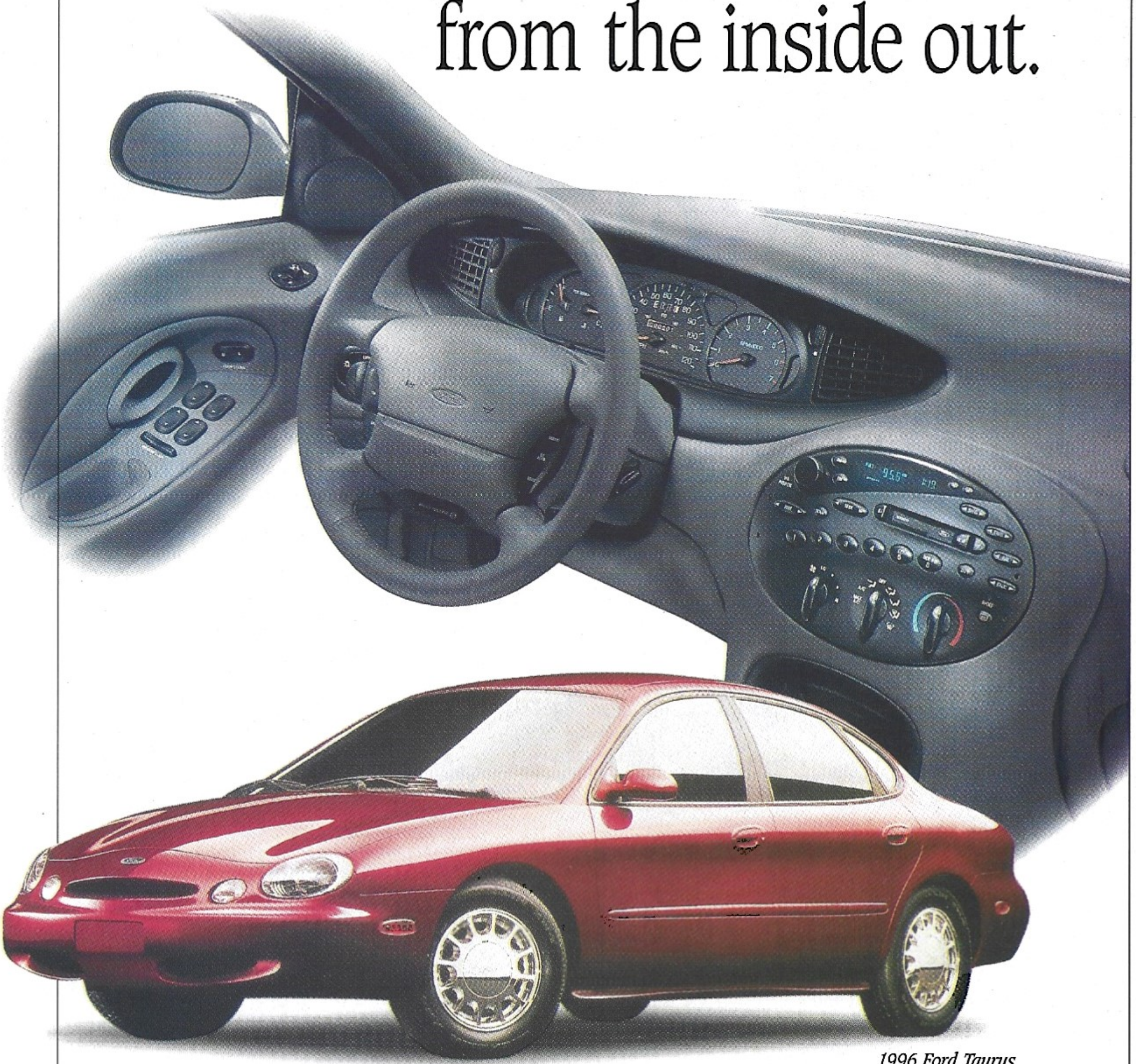
Filtered air and patented seats

The Interior Air Filtration System is particularly beneficial for allergy and asthma sufferers. Virtually all road dust and pollen less than 3 microns are filtered from the air before it reaches the passenger compartment.

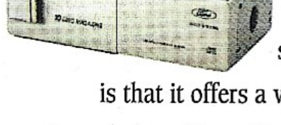
On the subject of comfort and convenience, many Ford vehicles now come equipped with a multifunctional console that holds cassettes and/or CDs, beverages, coins for tollbooths or parking meters, and other essential items. Some models even offer a patented front center seat that converts to an armrest. On certain Lincoln models, the front seat automatically slides back two inches when you remove the key from the ignition to make it easier to get out of the car. These seats return to a preset or original position, so there's no need to readjust the seat each time you get in and out. These seats are also engineered to warm to five temperature settings and adjust with four-way power lumbar support.

In addition to these technological innovations, Ford cars and trucks are packed full of other high-tech features and systems that make them more comfortable and convenient to drive. Our vehicles are so much like home, you may soon start receiving e-mail in them.

A new way to look at Taurus... from the inside out.

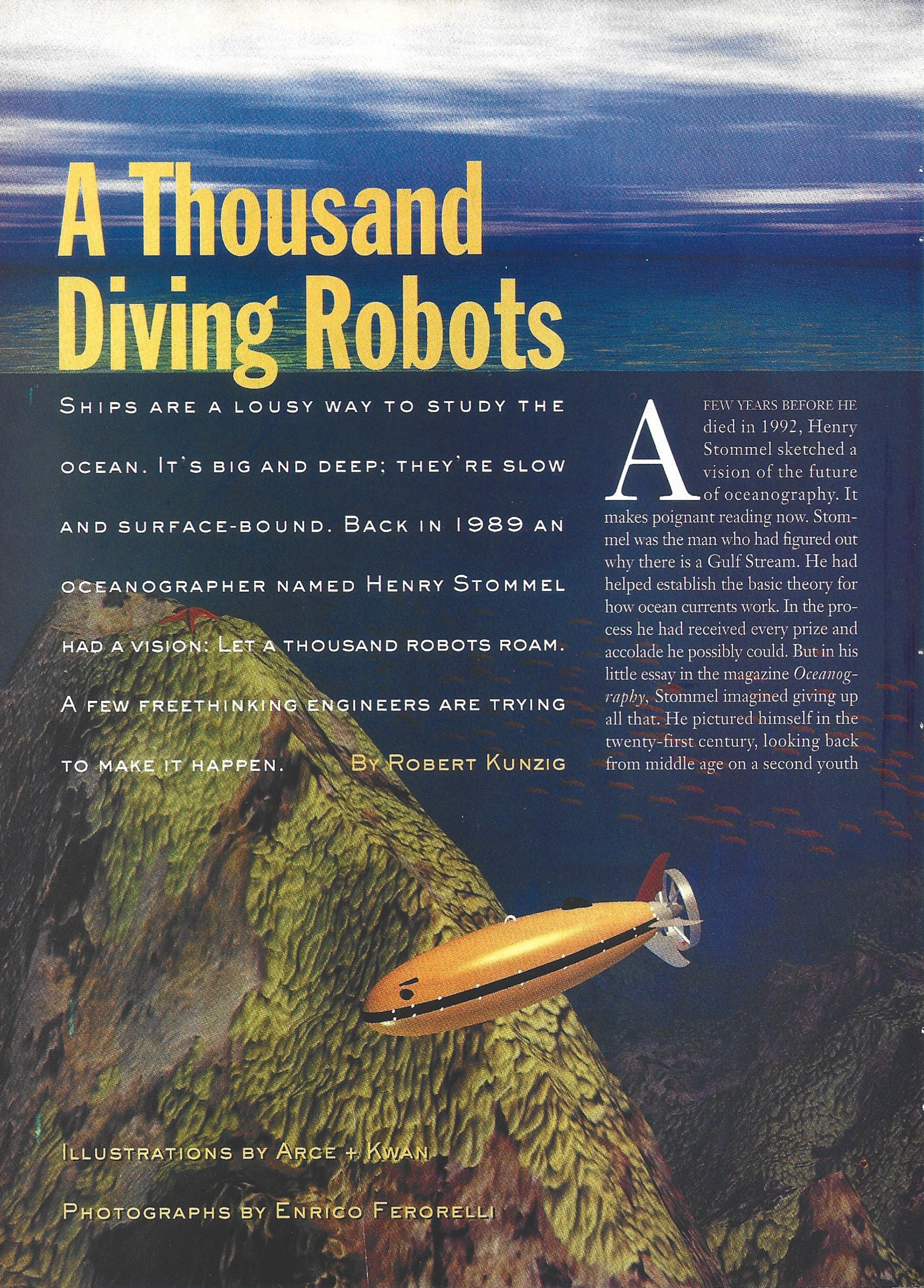


1996 Ford Taurus



Car audio systems are extremely important to overall owner satisfaction. One of the reasons Ford Taurus is the best-selling car in America is that it offers a wide range of audio choices. The optional Premium Sound or Ford Electronics/JBL Audio Systems are available with a factory-installed six CD changer or a dealer-installed ten CD changer. All of the Taurus audio systems are acoustically designed to maximize sound quality. The new Ford Taurus... it sounds as good as it looks.

Ford
ELECTRONICS
TECHNOLOGY WITH A PURPOSE®



A Thousand Diving Robots

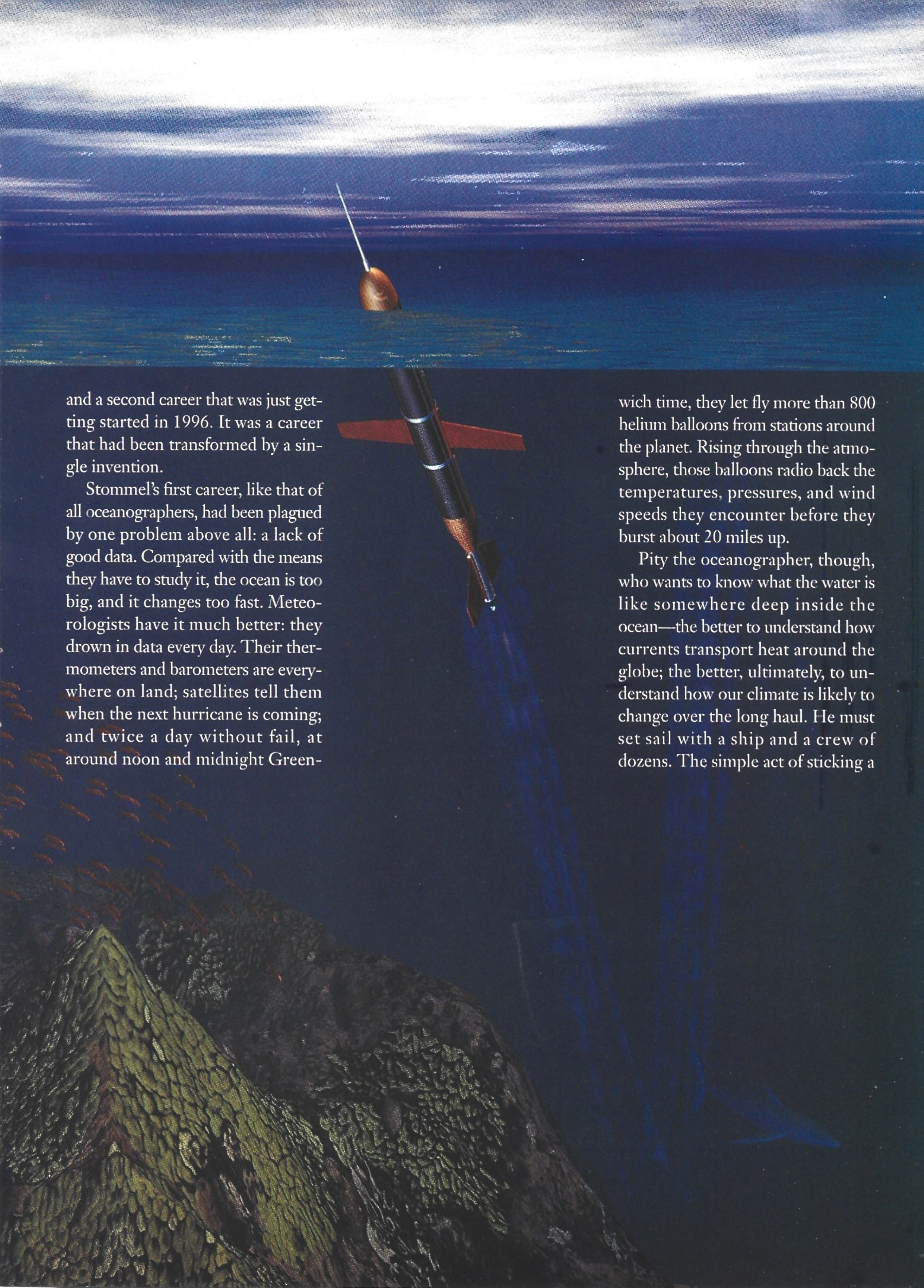
SHIPS ARE A LOUSY WAY TO STUDY THE OCEAN. IT'S BIG AND DEEP; THEY'RE SLOW AND SURFACE-BOUND. BACK IN 1989 AN OCEANOGRAPHER NAMED HENRY STOMMEL HAD A VISION: LET A THOUSAND ROBOTS ROAM. A FEW FREETHINKING ENGINEERS ARE TRYING TO MAKE IT HAPPEN.

BY ROBERT KUNZIG

A FEW YEARS BEFORE HE died in 1992, Henry Stommel sketched a vision of the future of oceanography. It makes poignant reading now. Stommel was the man who had figured out why there is a Gulf Stream. He had helped establish the basic theory for how ocean currents work. In the process he had received every prize and accolade he possibly could. But in his little essay in the magazine *Oceanography,* Stommel imagined giving up all that. He pictured himself in the twenty-first century, looking back from middle age on a second youth

ILLUSTRATIONS BY ARCE + KWAN

PHOTOGRAPHS BY ENRICO FERORELLI



and a second career that was just getting started in 1996. It was a career that had been transformed by a single invention.

Stommel's first career, like that of all oceanographers, had been plagued by one problem above all: a lack of good data. Compared with the means they have to study it, the ocean is too big, and it changes too fast. Meteorologists have it much better: they drown in data every day. Their thermometers and barometers are everywhere on land; satellites tell them when the next hurricane is coming; and twice a day without fail, at around noon and midnight Greenwich time, they let fly more than 800 helium balloons from stations around the planet. Rising through the atmosphere, those balloons radio back the temperatures, pressures, and wind speeds they encounter before they burst about 20 miles up.

Pity the oceanographer, though, who wants to know what the water is like somewhere deep inside the ocean—the better to understand how currents transport heat around the globe; the better, ultimately, to understand how our climate is likely to change over the long haul. He must set sail with a ship and a crew of dozens. The simple act of sticking a thermometer in the middle of the Pacific costs him, or rather his government, hundreds of thousands of dollars. Steaming across the ocean in a straight line, he stops every so often to repeat the same routine measurement at stations no oceanographer is likely to visit again for decades. It is tedious, expensive work—and it isn't done nearly often enough.

So Stommel imagined a machine that could do it. It would be the oceanographic equivalent of those helium balloons, only better. It would be a small, cheap, torpedolike drone that would glide around in the ocean on its own, with an ingenious new engine that would draw power not from batteries but from the ocean itself. Stommel envisioned a thousand of these robots porpoising through the sea at once, staying out for five years and collecting data with a few simple sensors. And several times a day each one of them would broach the surface to report via satellite to Mission Control.

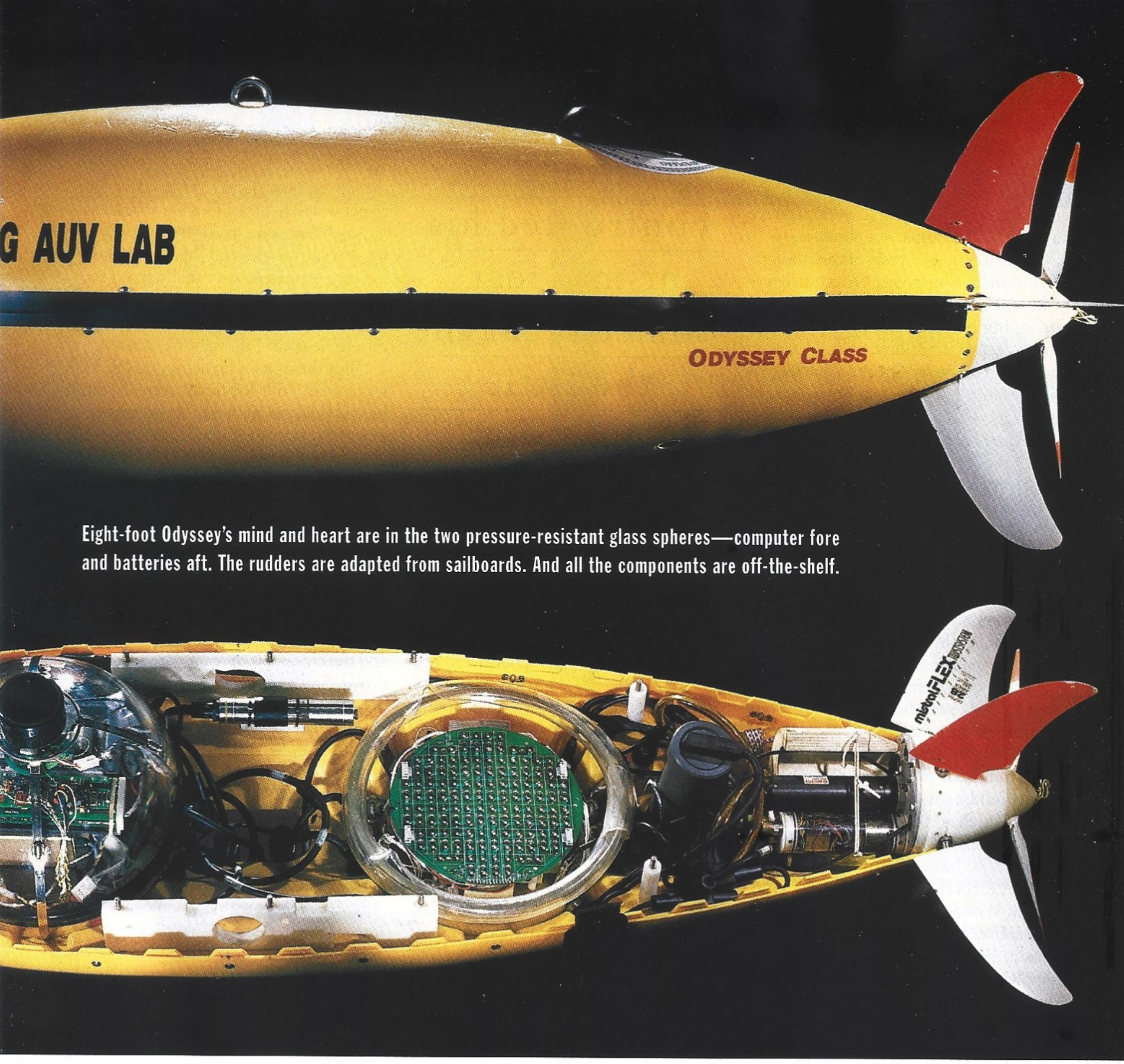
That is where Stommel would sit: on an unspoiled island off Cape Cod, not far from the Woods Hole Oceanographic Institution, where he had spent most of his first career. The island was to be a kind of sanctuary. It would have few permanent residents and no automobiles—just a narrow-gauge railway, like the one Stommel had once built in his own yard to amuse his grandchildren and himself. Outside the headquarters building, sheep would graze on the grass bank that sloped down to the sea; inside, virtual-reality displays would immerse oceanographers in the latest data from the scattered robot fleet. In Stommel's vision, twenty-first-century technology coexisted peacefully with the shade of Henry David Thoreau.

The right kind of technology, he thought, could set oceanographers free—free from the quiet desperation of lives spent looking for a ship; free to do the equivalent of designing Central Park, as Stommel once explained it, instead of just mowing the lawn. The robots would handle the lawn mowing: they would conduct on a continuous basis the routine surveys that ships could do only every few decades. Meanwhile, around 200 of them would be reserved to pursue the inspired whims of individual researchers—to track a pod of whales, say. "In my heart," Stommel told an audience of oceanographers at around the time he published his essay, "I believe that, for a scientist, it is his personal mental wrestling match with some aspect of the universe that is his central activity and reward. All alone, one confronts the unknown and divines some meaning from it." Just so would Stommel's robots confront the ocean alone, without a tether, each of them part amanuensis and part alter ego to the man who had dispatched them. They were to be called Slocums, after Joshua Slocum, who in 1898 had become the first man to circumnavigate the globe single-handedly. Before the robots settled down to science, Stommel planned for them too to race around the world.

He did not live to see the first one dunk its nose in the ocean. But last fall it finally happened anyway—for the Slocum was not Stommel's vision alone, or even primarily. The thing itself was invented in a cottage across the road from Stommel's house in Falmouth, just north of Woods Hole, by an independent engineer named Doug Webb. The device Webb and his colleagues dropped into the Atlantic off Bermuda in October was just a prototype—it only bobs up and down in the water rather than gliding through it—but it was the first sea trial of Webb's innovative engine, and it worked perfectly. Moreover, Webb is not the only engineer at work on an "autonomous underwater vehicle," or AUV; nor is his project even the furthest along. At MIT, for instance, a researcher named Jim Bellingham has built an AUV called Odyssey, in its own way just as thrifty and ingenious as the Slocum, that is already at sea doing science. Four years after Stommel died, it is beginning to seem possible that mariner-robots really will go down to the sea in large numbers one day—and that they may transform our understanding of this water-covered planet.

UNDERSEA ROBOTS WERE not always thought of as inexpensive tools for oceanographic research. When the first ones were conceived in the 1960s, the impulse behind most of them was military: the Navy wanted robots that could map underwater minefields laid out by the Soviet Union. To carry out so sophisticated a mission, it was thought an AUV would need a lot of computer power and a lot of batteries, and so it would need to be large. Draper Laboratories in Cambridge, Massachusetts, is still working on such a robotic mine scout; it is around 40 feet long and weighs seven tons, just about the size and weight of a *Tyrannosaurus rex*. To Jim Bellingham, a buoyant and boyish engineer who works down the street from Draper at the MIT Sea Grant laboratory, it is a dinosaur in other ways as well.

Around the time Stommel was writing his essay, in 1989, Bellingham was getting started at Sea Grant, his first job after graduate school. His Ph.D. was in physics, and his graduate work had involved superconductivity—but that turned out not to be what he wanted to do with his life. "Around that time the high-temperature superconductors were discovered," he recalls, "and that totally changed the complexion of the field. Conferences and workshops where there had been 50 people suddenly had 2,000 people, you know, from big semiconductor companies and big industrial outfits who were getting into the game.



Eight-foot Odyssey's mind and heart are in the two pressure-resistant glass spheres—computer fore and batteries aft. The rudders are adapted from sailboards. And all the components are off-the-shelf.

"On the one hand, it looked very lucrative, and on the other hand, it didn't look like there was much prospect for somebody to really make a contribution in a field when suddenly it had become so enormous. What I wanted to do was find a field where there was an enormous amount of promise but there wasn't an enormous amount of activity yet, because it was a little bit too far out. Where people said, 'Yeah, it will work, but maybe sometime in the next century.' "

AUVs met that requirement. So when Sea Grant offered him the job of building one, Bellingham grabbed it. His first toe into the water was Sea Squirt, a three-foot-long, 77-pound clunker that made up in ease of use what it lacked in elegance. Sea Squirt was a test bed: Bellingham and his students crammed it with sensors of all types. Above all, they used it to test a new approach to robot intelligence, called layered control, that was just then being pioneered at MIT by an engineer named Rodney Brooks.

The traditional approach to controlling a robot is to try to give it a crude version of human intelligence, along with a map of its environment; as the machine continuously updates the map with information from its sensors, it chooses from many possible actions the one most likely to lead to its goal. All that mapping and intelligent decision making, though, requires a lot of computer power, which makes for big, expensive robots. It also makes for a robot that, in a turbulent ocean, would be in danger of running onto the rocks while updating its map.

Layered control, in contrast, takes insects rather than humans as its models of intelligence. In place of a big central brain and a map of the world it puts a hierarchy of behaviors, each one independent of the others. One of Sea Squirt's priorities, for instance, was "obstacle avoidance"—not smacking into a rock. Any time the signals from its sonars seemed to demand it, that survival behavior could take control of the robot from the more goal-oriented behaviors, such as searching for a target. Bellingham and his crew found that layered control worked well in Sea Squirt (although deciding which behavior was to be in charge when survival was not at stake proved tricky). The little drone could navigate the Charles River, a few blocks from the Sea Grant lab, without sinking any sailboats and without sinking itself. It could even produce a survey of the water temperature.

After a couple of years of this, though, Bellingham's boss, Sea Grant director Chryssostomos Chryssostomidis, began prodding him to think deeper—a few miles deeper. The point, after all, was to explore the ocean, not the Charles. To dive to the ocean floor, a robot needed to be able to withstand the immense pressures produced by the several miles of water above it. As Bellingham started to ponder this problem, he knew he had to ponder on a budget. Sea Grant was not the Navy, and the Navy, funder of behemoth AUVs, was not impressed with Sea Squirt. The question facing Bellingham was this: Would it be possible to build a robotic submarine that would dive to the ocean floor, do something useful, and come back alive, all for, say, $50,000?

The money constraint forced Bellingham to think new thoughts. His first one concerned the robot's hull. The conventional way to protect an AUV's insides from hundreds of atmospheres of pressure would be to build the hull of titanium, which is strong, corrosion-resistant, and relatively light—but a titanium hull would have blown Bellingham's budget directly. Nosing around some labs in Woods Hole, he came across an alternative: glass. A company called Benthos in Falmouth does a brisk business supplying oceanographers with 17-inch-diameter glass spheres for housing instruments on the ocean floor; when the spheres are sealed, they are strong enough to withstand a full ocean of pressure. And they cost only a few hundred dollars apiece.

Once Bellingham discovered the Benthos spheres, his deep-ocean robot quickly began to take shape. One glass sphere, he decided, could hold the personal computer containing the robot's insectlike brain, along with a compass and pitch-and-roll sensors for navigation. Another sphere could hold batteries to power the electronics and the motor. Mount the two of them in a hard-plastic frame and you have the nucleus of an AUV. The motor and most of the sensors you might need—the sonars, the camera, the temperature and salinity sensors—could be arrayed around the glass spheres; they did not need to be inside. All those things come with their own pressure housings when you purchase them from marine equipment manufacturers—in fact, it is more expensive to buy them without. With Benthos spheres and off-the-shelf gear, Bellingham realized, he could do without a watertight titanium hull. He could just slap a plastic fairing around his gear to give it a nice aerodynamic shape—cost: $2,000—and let the water flood into it. The rudders at the tail were a nice finishing touch: they came from a sailboard manufacturer.

> Sitting in a rubber boat, Bellingham confronted his primal fear: someday maybe the little bugger won't come back.

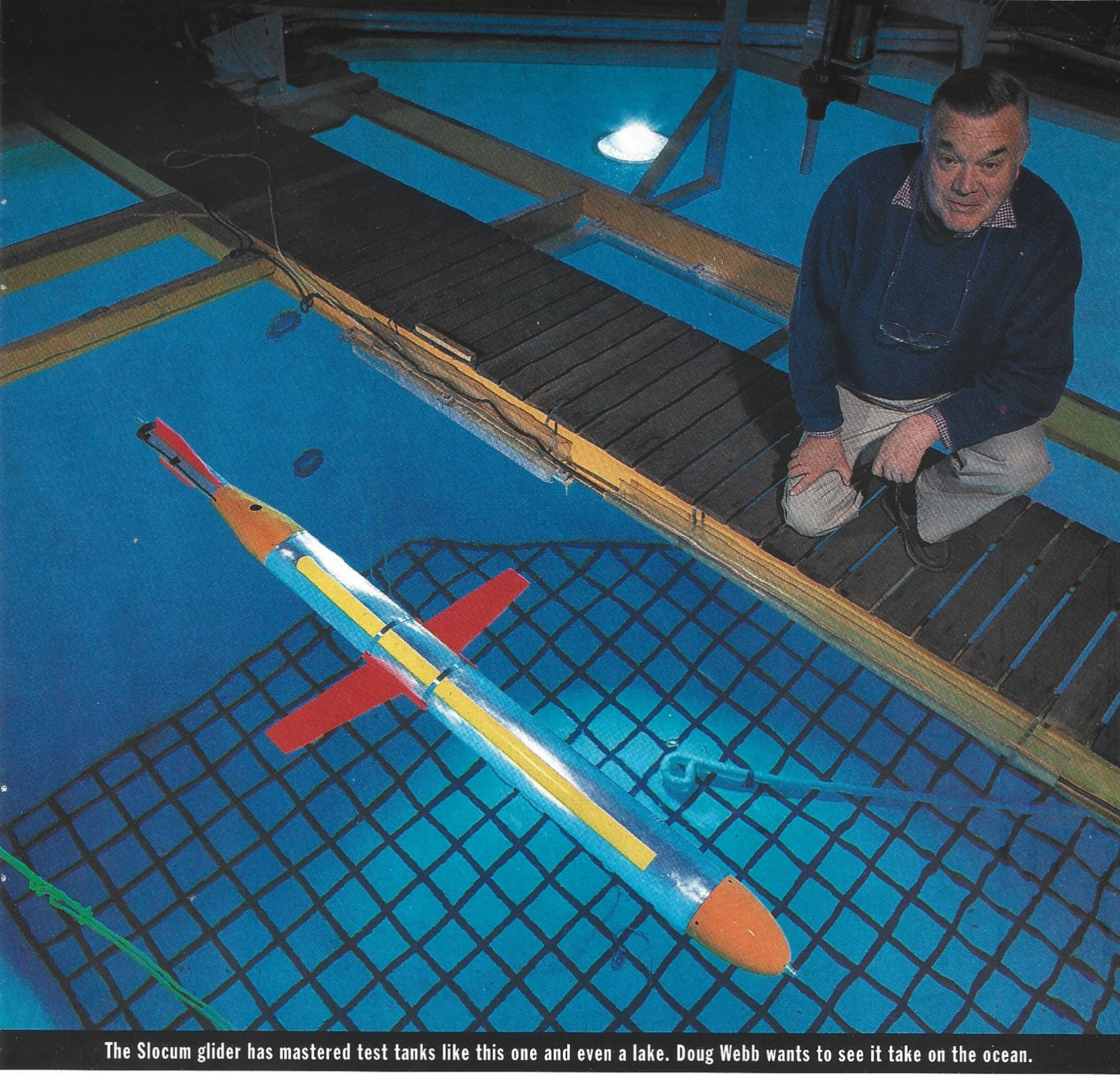
THE RESULT WAS ODYSSEY, an eight-foot-long, 350-pound submarine that soon outgrew the Charles. Its first trip to sea came in 1993, when an oceanographer friend at MIT invited Bellingham and his crew along on a cruise to the Antarctic. Sitting in a rubber boat in the white-capped Drake Passage, running Odyssey from a laptop computer cradled on his lap, Bellingham got a chance to confront the primal fear of any AUV builder—which is that someday maybe the little bugger won't come back. On the first two dives, everything went fine. Then came the third. "It turns out acoustic conditions were such that I lost tracking on the vehicle as it came up," Bellingham recalls. "Well, you figure, 'This is not so bad. We'll spot the vehicle again when it comes up to the surface.' We had a radio direction finder too, and we had a strobe—we had three different location devices. By this time, it's our third run, so we're feeling a little more confident.

"Well, the problem is, the darn vehicle should have surfaced, and we're not picking it up on the radio direction finder, and we're not picking up the acoustic beacon, and it's daylight out, so the strobe is no good anyhow. So I start to get worried. I start looking around for it. And pretty soon we have everybody up on the ship with binoculars out there looking for it. It wasn't really that long, maybe an hour total, that we couldn't find the vehicle—which to me was a very miserable hour. I thought we'd lost it.

"But the captain finally spotted it. He was looking out for birds, actually, and he saw this one giant petrel that was circling the sky for a while, and then it would land on the surface for a bit. And then it would take off again and circle in the sky. He saw this a couple of times and looked under the bird—and sure enough, there was the vehicle. What happened was, as this big bird would land on our vehicle, it would drive it underwater. It's slowly drifting back up to the point where it's breaking the surface again—and the bird lands on it and drives it back down. So the radio beacon is now underwater and you can't pick it up. How do you plan for that?

"Of course, the other thing wrong was, in the Charles a white vehicle is easily visible. In the Drake Passage, with breaking waves all over the place, a white vehicle is invisible. Which is why all our new vehicles are yellow."

In Antarctica, Bellingham proved not only that he was willing to put his baby at risk but also that he could make it work in the ocean. After that his phone started ringing. People wanted to work with him. Even the Navy got interested—which is how, a little over a year after the Antarctic trip, Bellingham found himself at the other end of the world, 150 miles off the North Slope of Alaska at a Navy ice camp in the Beaufort Sea, carrying a rifle in case of polar bears. In the Arctic his faith in his own engineering was put to an even sterner test: Odyssey proved that it can be dropped through a hole cut through the six-foot-thick ice, cruise around for a while, and then find the hole again. The Navy now wants to use Odyssey to study how the polar ice tends to break up—a poorly understood process that is of interest for submarines navigating under the ice and that also affects how Earth will respond to global warming. Bellingham didn't get to do too much of that research on his first trip to the Arctic, though: the ice camp itself broke up after two weeks.



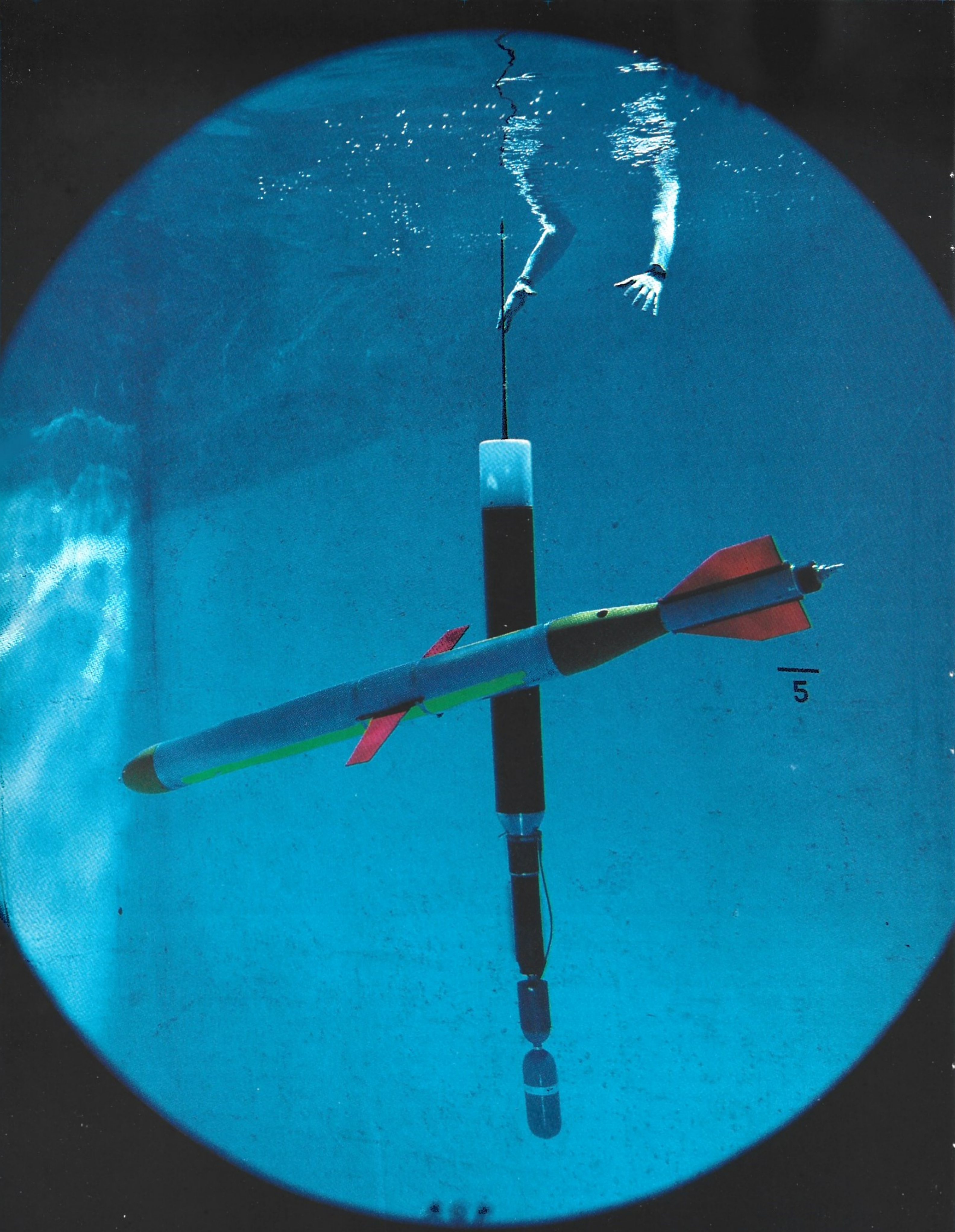
The Slocum glider has mastered test tanks like this one and even a lake. Doug Webb wants to see it take on the ocean.

Last summer Odyssey made its deepest dives yet, plunging nearly a mile into the Pacific off the coast of Washington, onto the crest of a volcanic mountain chain called a midocean ridge. Once the oceanographers he was working with have an Odyssey of their own, says Bellingham, they won't have to wait their turn, every year or two, to take a research ship out to see the volcanoes; as soon as their seafloor listening devices tell them an eruption has begun, they will simply load the robot onto a fishing boat and be out at sea taking pictures within hours. Bellingham expects a lot of research institutions to have Odysseys of their own eventually. His lab has already built half a dozen of the robots and is in the process of licensing the design to a private company that supplies the oil industry with offshore equipment. Apparently Odyssey has a future in monitoring undersea pipelines for oil leaks.

"Getting things off into the commercial world and used on the broader problems of society—I'd view that as a real feather in our cap," says Bellingham. "Particularly since it will be the first AUV that has actually gone into commercial production. I mean, that's a big deal. If you look at the history of flight, for a long time lots of people were building airplanes, but none was a commercial success. Then finally the DC-3 came along. If we end up with the DC-3 of AUVs, then we will have made a difference."

Odyssey is certainly as flexible as the DC-3, because its design is so thoroughly modular. Sensors can be added or subtracted to fit the mission; secured inside the yellow fairing, they don't affect the vehicle's performance in the water. Different behaviors can be added to the software without rewriting the whole program; Bellingham did it sitting in his tent one day at the ice camp. And a third glass sphere can be added and filled with batteries to extend the range of the vehicle to 100 miles or so.

On the other hand, that range is still relatively short. It means that Odyssey



A Slocum profiler—with a thermal engine but no wings—is now bobbing up and down off Bermuda. Here it bobs behind the glider.

will generally be operated in a limited region, going off on forays that last a few hours or a few days at most before it returns to the mother ship or goes to an underwater docking station where it can recharge its batteries. Whereas what Doug Webb and Hank Stommel had in mind was a robot that would do without a ship entirely and stay out for five years, longer even than Joshua Slocum himself.

STOMMEL ONCE WROTE A profile of his friend Webb for *Oceanus*, a magazine put out by the Woods Hole Oceanographic Institution. "Doug Webb appears to be a cautious and deliberate man," the piece began, "but his career shows that he is actually unusually daring." Webb certainly does not fit the movie image of a daredevil. He is 66 now and stocky, with a thinning thatch of hair covering his broad head. He has a taste, in summer, for shirts with epaulets and Bermuda shorts that do not hide his skinny legs. He does not seem like a man who would leave his native Ontario at age 23 to go to Manchester University in England to work in a lab that included Alan Turing, the computer pioneer; nor like a man who would spend part of his time there racing Bugatti sports cars; nor yet like a man who would drop academia and go off to work on computers for Olivetti, the Italian office-equipment manufacturer. Least of all does he look or sound like a man who would ever speak Italian. His manner, though not aloof or unfriendly, is careful and even formal. Stommel once said of himself that he had chosen a career in the physical sciences—he had also considered the ministry—because he was convinced that he was "emotionally better adapted to dealing with physical laws than with human affairs." One senses in Webb a similar uncertainty about how best to deal with recalcitrant human materials. "I try to be careful not to be threatening," he says.

People are not always what they seem on cursory acquaintance to be, however, and Webb loved Italy. He and his wife, Shirley, whom he met when they were chemistry lab partners in high school, lived there for six years and might have stayed for good had not family ties pulled them back to North America—family ties, and Webb's urgent desire for a career change. "By that time," he says, "by 1962, believe it or not, it was clear to me that the computer industry was going to become quite large and that I was going to be a specialist in that industry. Computers were initially a place for generalists, and I decided I was more cut out to be a generalist. I made up a list of industries that I didn't think would go through that cycle, and oceanography, I thought, would offer opportunities."

The opportunity Webb found in 1962 was at Woods Hole, working as an engineer with physical oceanographers—the ones who study ocean currents. One of the basic methods such researchers use is to track currents with things that float. Not so long ago those floats were cards or bottles with messages in them, but today they tend to be more sophisticated devices. At Woods Hole, Webb became known as a master float builder. His most famously successful creation was the SOFAR float. SOFAR stands for Sound Fixing and Ranging, and it refers to a layer of the ocean, typically around 3,000 feet below the surface, that tends to trap sound and channel it over long distances. Following up on an idea tossed off by Stommel in 1949, Webb and an oceanographer named Tom Rossby built a device that could drift along on a subsurface current, all the while emitting huge booming sounds that would travel through the SOFAR channel and allow faraway oceanographers to track the float. In the 1970s and 1980s, researchers chucked hundreds of SOFAR floats into the ocean—although *chucked* is perhaps not the right word: a SOFAR float weighs half a ton and is around 25 feet long, most of it aluminum piping. In the profile Stommel wrote there is an old photo of Webb standing on the dock at Woods Hole next to an upright SOFAR float, looking proud and very small.

"He's a giant," says Bellingham. "I had heard about him long before I met him. You know, there are people who have great ideas, and then there are people who really have made things work. His floats are almost at the point where they don't seem like a big deal anymore. It's like 'Oh yeah, there's a hundred of those out there.' 'Yeah, and they all work.' He's the guy who made them work and had the vision to create them."

The vision of Slocum came to Webb slowly. In 1974, while he was still in the throes of the SOFAR project, he first started thinking about an AUV that could cross the Atlantic under its own power rather than drifting at the mercy of the currents. But it was not until 1988, while working on a SOFAR spin-off called the Bobber—a float that could bob up and down in the water as it drifted along—that Webb saw where that power might come from. Every time the Bobber wanted to ascend, it inflated an external rubber bladder with oil pumped from an internal reservoir; this increased its volume without changing its mass and so made the float more buoyant. When it was time to descend, the Bobber simply transferred the oil back to the internal reservoir and sank. The work was done by a battery-powered oil pump. Webb realized there was a more natural way to make something expand and contract: you could just heat it and cool it. Maybe, it occurred to him, there was some way you could power a bobbing AUV by drawing heat out of the ocean and then putting it back. "That was my first glimpse of thermal propulsion for an underwater vehicle," he says. "The Bobber was a very intensive project, though, and I didn't have time to stop. But when it was over, I went back and I picked up those loose threads."

Then he had his second idea. The dream, after all, was not just to build a better Bobber; it was to build a robot that would cross the Atlantic. Once you have it bobbing up and down, though, it is easy—conceptually, anyway—to make it move horizontally as well: you just put wings on it and let it glide. As the robot fell through the ocean, water flowing over those wings would generate lift, which would carry it down and forward rather than straight down—let a paper glider fall from your hand and you will see it is true. At some nadir in the depth, the glider would then change its buoyancy and start climbing again. All the while its thermal engine would be refueling on the fly: at the warm, sunlit surface it would draw heat from the water; in the cold depths it would put the heat back. Flying for free, without need of batteries for power, the robot could cruise across the Atlantic. In principle it could go around the world.

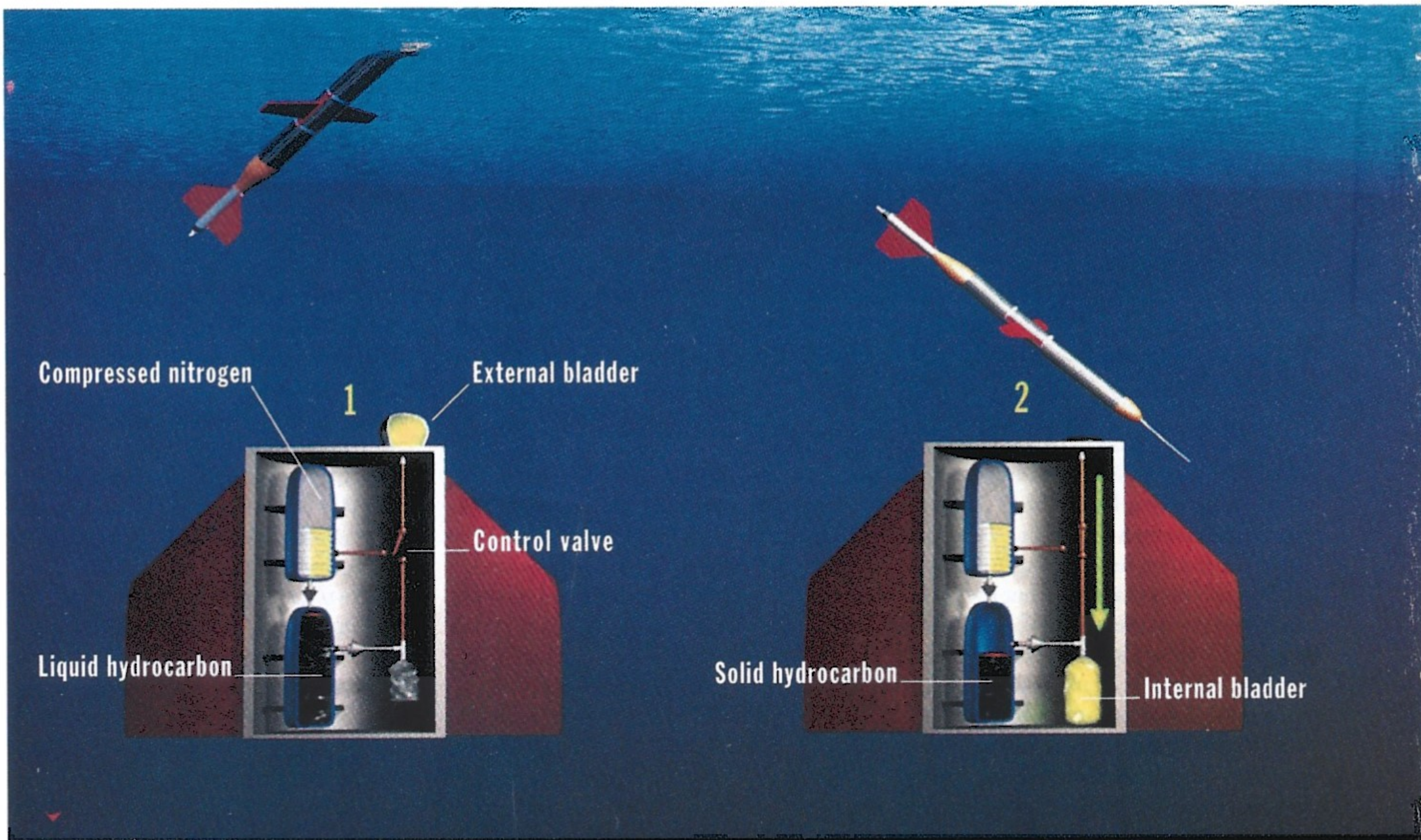
The whole concept was simple and beautiful and—as Webb would put it—sweet. Webb sensed he was onto an idea that would be a nice way to close out his career. By this time, though, he had long since abandoned the structured security of the oceanographic institution to start his own float-building company, Webb Research, in the cottage behind his house. He was a businessman now, dependent on contracts obtained from oceanographers, who in turn had to get grants from the government. He employed half a dozen people, including his son. His ideas had to pay salaries. He might have 10 or 20 inventions knocking around his head at any one time, but for any one of them to go anywhere, an oceanographer had to get excited about it. Making the rounds in 1988 with his thermally powered ocean-crossing glider scheme, Webb didn't have much luck, in spite of his track record. The idea was too radical to be greeted with anything but skepticism.

So at some point in the proceedings Webb took the obvious step: he walked across the street to Hank Stommel's house. It was a well-trodden path in both directions. The two men had been going to sea together for decades, and they had been neighbors on land since 1966, when Webb bought his house from Stommel and Stommel moved across Palmer Avenue. Their personalities were not at all alike. Stommel was gregarious and open and always bubbling with ideas, which he gave away freely to less gifted colleagues; Webb was and is careful and shy and nervous about collaboration. And yet there was a deeper commonality between the two men. It had its roots, perhaps, in the fact that both were inventors. Webb invented machines, Stommel invented physical theories—but a theory is not so different from a machine. It is designed to solve some problem, and it has parts that have to fit and work together. It can be simple and elegant—as Stommel's explanation of the Gulf Stream was—or complex and unwieldy. It can be a radical departure from the past—as Stommel's theory of powerful deep ocean currents was in the late 1950s, when most people thought they didn't exist—or a modest elaboration of it. Webb and Stommel both liked the simple and the radical. They shared an aesthetic. They found the same things sweet.

Flying for free, without need of batteries for power, the robot could cross the Atlantic—and even go around the world.

And along with the aesthetic went an ethic. If what you strive for is simplicity, and if your aim is to put something truly new in this world, then it is best not to be an organization man, because large organizations are seldom sympathetic to overly inventive individuals. "People feel threatened by inventors," says Webb. "They change the world, and all the things that you've done might be made obsolete. Most people would like things to go on just about the way they are, and make incremental changes to keep ahead. If someone comes along and says, 'I'd like to make some big change over here'—God! You know, all that investment is gone, and all of that database is worthless.

"I think it's a human thing, not just a scientific thing. In engineering, in com-



A dive with Slocum, with the thermal engine in its tail shown schematically: When liquid glycol (green) fills the external bladder (1), Slocum is buoyed to the surface. To dive, a three-way control valve is closed, allowing the glycol to flow into an internal bladder (2). The cold temperatures at depth freeze the liquid hydrocarbon into a solid, creating a space that is filled mercial enterprises—Ford and General Motors and Chrysler are just kind of incrementally trying to find some advantage with respect to the others. They don't want anything radical to appear. That upsets everybody in a big way.

"Well, that never troubled Hank."

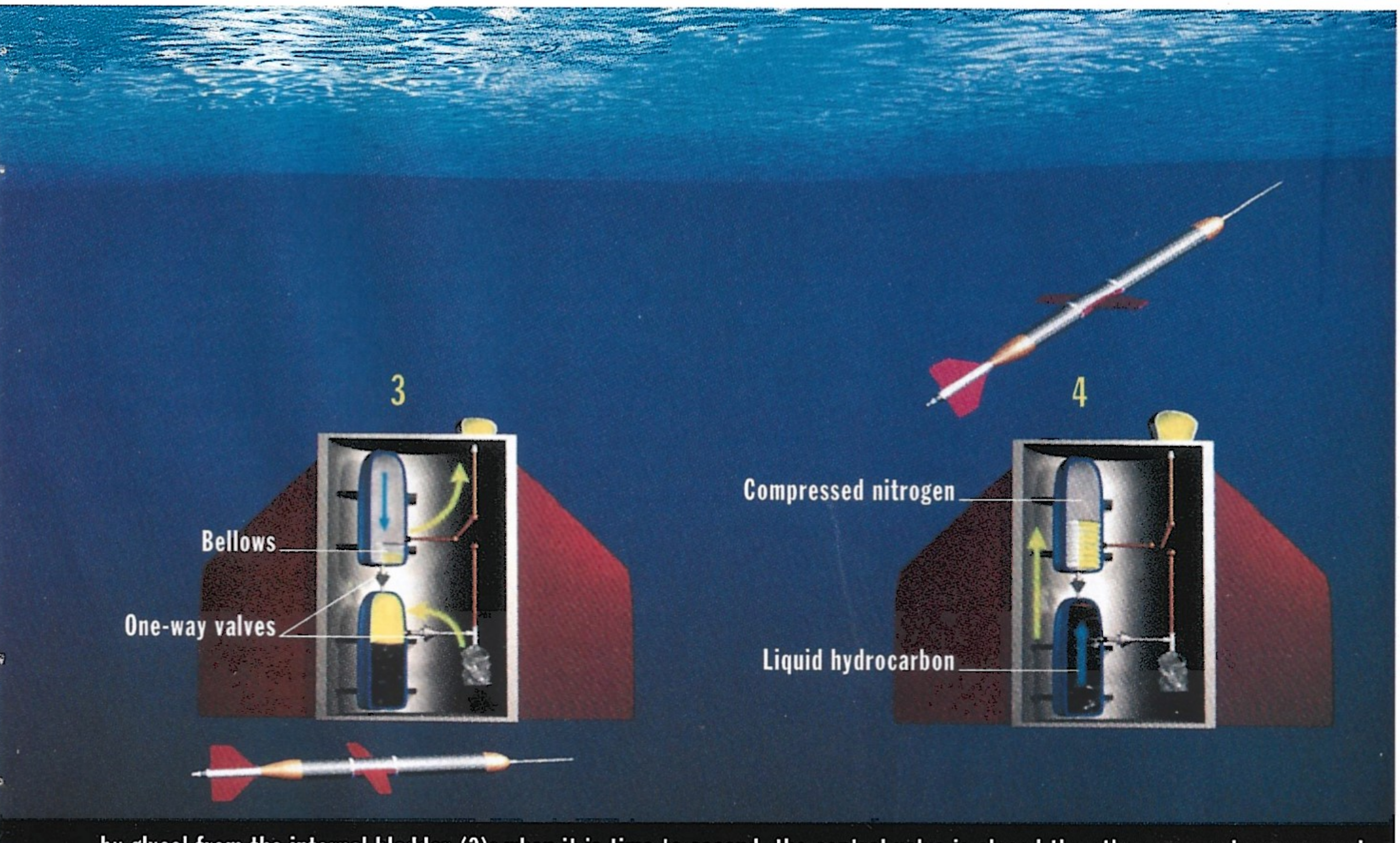
Stommel was interested in Webb's thermally powered AUV right away. One of his many passions was steam machinery—in his backyard he kept a Canadian Pacific railroad whistle, with which he would periodically startle the neighbors—and what Webb was proposing was analogous to an underwater steam engine. In a steam engine, as water changes state from a liquid to a vapor—at precisely 212 degrees Fahrenheit—its volume expands by a factor of 1,800, and that expansion drives a piston that turns the engine. The heat to make the steam comes from burning coal.

Webb's AUV wasn't going to be coal fired, of course, and it wasn't actually going to use steam. He had in mind a different working fluid, one that would change from solid to liquid as its temperature rose from around 40 degrees Fahrenheit to around 60 degrees—which is what would happen as the robot climbed from a mile deep in the ocean up to the surface. As the solid expanded to a liquid, it would be made to compress nitrogen in a neighboring tank. That compressed nitrogen would store energy, the way a coiled spring does. When next the robot was a mile deep and wanting to climb, a flip of a valve would allow the nitrogen to uncoil and push oil into an external bladder. The inflated bladder would buoy the robot back to the surface, just as it had done to the Bobber—only now the work would no longer be done by a battery-powered pump. The robot would still need a few batteries to power the crucial valve, as well as its steering mechanism and the radio it used to talk via satellite with its human masters. But it would get its propulsion for free.

NOTHING LIKE IT HAD EVER been built before, which must have recommended the idea to Stommel. He began to get seriously excited, Webb recalls, when Webb mentioned the possibility of round-the-world robot races. It was then that Stommel suggested naming the robots after Joshua Slocum, and it was then that he wrote his little essay in *Oceanography*. He was hoping to get his colleagues excited about the idea, too. Meanwhile, to get the project started, Stommel persuaded the Navy to give him a three-year development grant, with a subcontract to Webb.

The money allowed Webb to start work on some of the hurdles Slocum would need to leap on its way from the drawing board to the ocean. To begin with, Webb had to find the right working fluid. The solution he came up with, after long hours of leafing through the pages of the *Handbook of Chemistry and Physics* and experimenting in his shop, was a pure hydrocarbon, one that at low temperatures forms a waxy solid, much like paraffin. But at precisely 50 degrees Fahrenheit the wax melts, and when it does, its volume expands by 10 percent. That expansion, Webb calculated, would be enough to compress the nitrogen and ultimately to pump a slug of liquid glycol into the external bladder, against crushing deep-sea pressures.

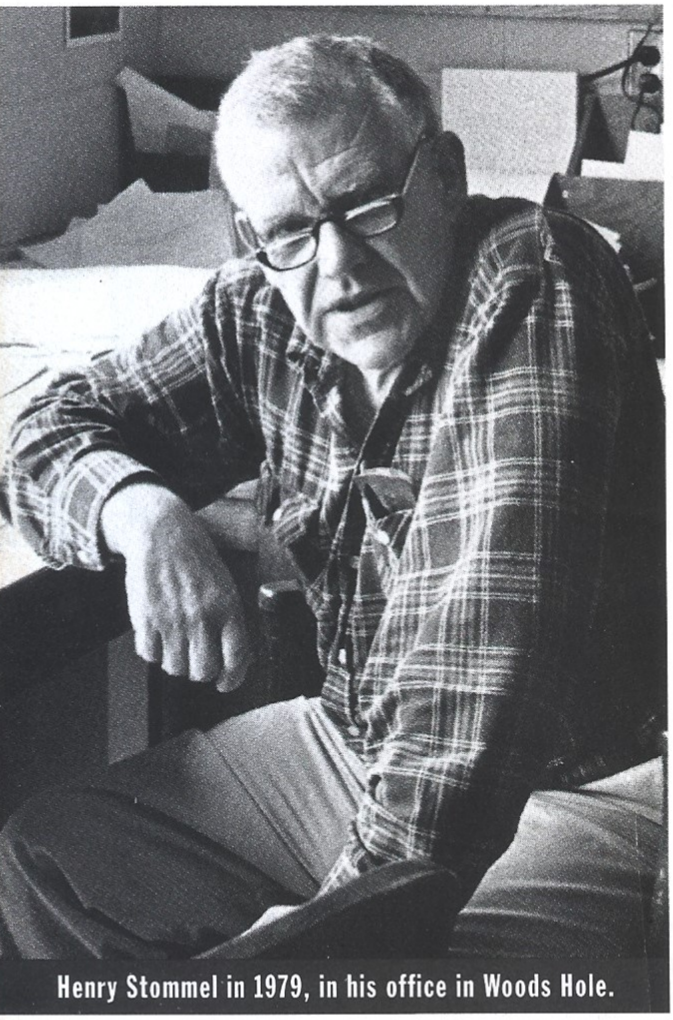
The inflated bladder would provide a buoyancy force of around four ounces to



by glycol from the internal bladder (3); when it is time to ascend, the control valve is closed the other way, and compressed nitrogen from the top tank pushes glycol out of a metal bellows into the external bladder. During the ascent, as the hydrocarbon melts again, it pushes glycol back into the bellows, compressing the nitrogen and readying Slocum for the next dive (4).

the 90-pound Slocum. That is not much in the way of propulsion: it would push the little robot to only half a knot—a speed so slow it raised a whole new set of problems. Could a glider move that slowly and still remain stable? Could it navigate a course and turn when commanded to do so? And could it do all that without the wing flaps and other movable control surfaces an airplane relies on? Such control surfaces, Webb decided, would gobble too much battery power; they would wear out over a five-year mission; and because they would have to be connected to their motors through holes in the fuselage, they would be apt to cause leaks. Slocum would fly with fixed wings and tail.

In a way, it would be much more like a blimp than a heavier-than-air plane. An airplane is kept aloft by the force of air rushing over its wings, whereas a Slocum, like a blimp, is simply less dense than the fluid below it, so it floats. To ascend and descend it adjusts its buoyancy slightly—and it could steer, Webb decided, by making equally minute adjustments of its center of gravity. The sloshing of a few ounces of liquid glycol in and out of the external bladder would be enough to point the probe's nose up for the ascent and down for the descent. To bank to one side, Slocum would rotate the stack of D-cell batteries it carried at its midsection; because of the way the batteries were arranged, that action would move the center of gravity slightly to one side of the robot's central axis, causing its left or right wing to roll. For this system to work, however, the weight of each component of Slocum would have to be known to within a fraction of an ounce, and its position to within a fraction of an inch. It would all have to fit together just so.



Henry Stommel in 1979, in his office in Woods Hole.

Vicky Cullen/Woods Hole Oceanographic Institution

Having the great idea, Webb knew, was just the beginning. "It's always possible that we will run into some problem that is essentially terminal," he said in the spring of 1991, when he was still in the thick of his personal mental wrestling match with Slocum. "And in the first half-year of working on this, I was concerned about one day coming in and spotting that terminal flaw. Now I think it's much less likely, although instead we may find something that's a serious compromise—that makes it heavier, uglier than I first hoped. The great fear is that you start off with a very simple concept, and you run into a problem, and you add some complexity here, then you find another problem and add some complexity over there. And before you're finished, it turns out not to be simple, but really very complex, expensive, and difficult to handle."

It was an intense period, those first two years of the project, with Webb trying to spend as much time as possible on Slocum without neglecting the other floats that were his company's bread and butter. Sunday mornings would often find him over at Stommel's house, talking Slocum while Stommel's wife, Chickie, was playing the organ at church. During the week Stommel would sometimes stop by Webb's cottage when he came home for lunch. "Hank enjoyed walking across the street to our shop and seeing what was going on—because something was happening there," Webb recalls. "If you've worked, as he did, almost entirely in your head, it's sometimes nice to see some fast results."

In the end the results did not come as fast as either man wished. But by the fall of 1991 Slocum was ready for its first real test, in Lake Seneca in upstate New York—the most readily accessible body of water, aside from the open ocean itself, that was deep enough and cold enough to give Slocum a gallop. The engineer Webb had hired to work on Slocum, Paul Simonetti, had already tested the glider in a shallow, crystal-clear lake in Florida, watching it through a glass-bottom boat. Now he and Webb were going to let Slocum out of their sight for the first time. Before loading it into the van for the trip, Webb brought it across the street to Stommel's house. He carried it into the kitchen to show Chickie Stommel what all the fuss had been about. It was, she remembers, a happy and very exciting day.

At Lake Seneca in November, Simonetti and his colleague Josh Hunt found two feet of snow on the ground and a 29-foot motorboat for rent cheap. The sky was overcast, the water was calm, there was no traffic on the lake, and Simonetti and Hunt were really quite confident when they dropped Slocum over the side for the first time and watched it sink slowly out of sight. In test tanks it had responded vigorously to their commands. But they also had a fail-safe mechanism. "We had put a lot of work into this thing, and we didn't want to lose it," says Simonetti. "With these things, you never can tell what's going to happen—something totally absurd may happen. So what we did was, we had a little buoy on the surface. On the tail end of the vehicle we had a spool of fishing line that would just pay itself out without any tension, and we attached the other end to the buoy. So in case it did fail, we could get it back just by pulling up the line."

It never came to that. Simonetti and Hunt tested the glider again and again, and Webb joined them after a few days for more tests. They programmed Slocum to go one way, then threw it in the water pointing in the wrong direction and watched as the autopilot software banked the glider and brought it around until it was pulling the surface buoy on the programmed course. Once the robot found that course, it stayed on it; it didn't toss around at random. And it always came back to the surface.

For those tests Webb and his colleagues didn't have the thermal engine in their glider; they had a battery-powered pump. The thermal engine had been tested separately in Lake Seneca, in a device that just bobbed straight up and down, and it had worked well. The engineers had wanted to test each technology separately before taking the risk of marrying them. Driving back to Woods Hole in mid-November, though, they knew they were ready to put the whole thing together. They believed now that they really were going to be able to build a glider that would cross an ocean. Another year or so of development work ought to do the trick. Two months later, in January 1992, Hank Stommel went into the hospital to undergo surgery for liver cancer and never came home. He was 71.

“IF IN THE MIDST OF AN OFTEN crass and strident society, we have learned to love this world, if we have managed to control our avarice and learned to give rather than take, and above all to give ourselves to fellow human beings, then we may discover how, with grace, to give ourselves to death.” Stommel had written those words in a column for the local newspaper in 1985, after his first battle with cancer. After his death the column was reprinted in a special issue of *Oceanus,* along with the reminiscences of scores of people who had known him over the years. In tribute after tribute, people remarked on his generosity, his manic energy, his pyromania (he was a fireworks impresario), and his mechanophilia (to clear brush from his pond, he once bought a coal-fired steam shovel from a shipyard in Boston). Shirley Webb, Doug's wife, recalled Stommel the painter, who showed the influence of Henri Rousseau and was surprisingly proficient in a rambunctious, childlike way. On one canvas from his “disaster period,” a grand old hotel near Stommel's house is on fire and a fireman is being chased by a rhinoceros while other East African animals look on. “Hank would often appear at our kitchen door at unlikely times, with a book, an idea, or a bag of fruit or vegetables. . . ,” Shirley Webb wrote. “He would sit and visit, then disappear abruptly, thinking a new thought, probably.”

Doug Webb did not contribute to the *Oceanus* volume. “Hank's death was traumatic both personally and professionally” is all he will say. Webb's business, though, has prospered since 1992. He has had great success with a bobbing float called ALACE, hundreds of which are now drifting around the world's oceans. He has been able to move his company out of his cottage and into a new headquarters building. Everyone at Webb Research has an office now, and there is a well-appointed conference room. A plaque on the door identifies it as the Stommel Room.

Before Webb retires, he would like to see Slocums porpoising through the ocean—chasing eddies, cruising the meridians.

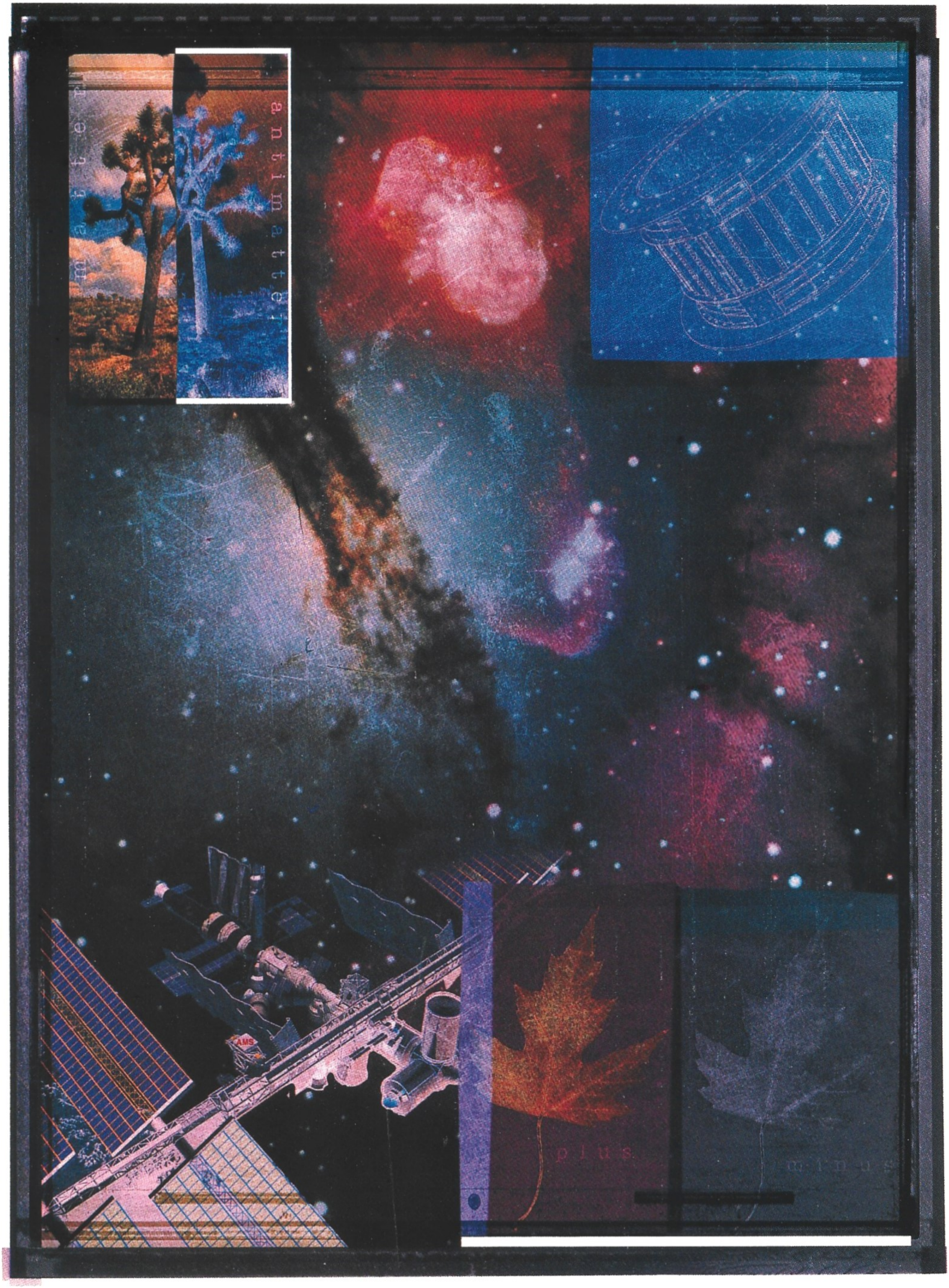
But Slocum hit the doldrums after Stommel died. In the summer of 1992 the Navy did not renew its funding of the project. Slocum can operate only where it has deep, cold water to dive into, and after the Persian Gulf War and the collapse of the Soviet Union, the Navy's interest shifted to shallow-water oceanography. Had Stommel been around, the Navy might have been inclined to renew his grant anyway; but Stommel was no longer around.

Webb didn't give up, though. He put the development of the glider on hold, but he kept Simonetti working on the thermal engine, paying his salary out of internal funds. His hope was that there might be scientific interest in a profiling device that would simply go straight up and down in the ocean—and for five years, thanks to its thermal engine. He turned out to be right. The National Oceanic and Atmospheric Administration came forward with a small grant, and last October the first prototype profiler went into the ocean off Bermuda. As of early February it was still working, sinking down to 4,500 feet and rising back to the surface every two days, and radioing its temperature measurements back to Webb Research via satellite. Apparently Webb's thermal engine works in the ocean too, not just in Lake Seneca.

Meanwhile the glider has finally emerged from enforced hibernation—at least the battery-powered version that was tested in Lake Seneca. Unlike a thermal Slocum, it can glide in shallow water as well as deep. The Navy, which is already committed to Jim Bellingham's Odyssey, has decided that an electric Slocum glider might be a useful partner to it. Early this year the Office of Naval Research awarded Webb a subcontract to build electric gliders for a large experiment that is scheduled to begin later this year in the Labrador Sea. The Labrador Sea is one of just a few places in the world where deep-ocean currents are born from the sinking of cold, salty water—a sporadic process that has a large influence on Earth's climate. The electric gliders will sweep through the area, measuring the temperature and salinity variations that cause water to sink in narrow chimneys. When they find something interesting, an Odyssey will be dispatched to investigate in more detail.

Webb likes the Labrador Sea experiment; he thinks it is daring. And he admires Odyssey and Bellingham's off-the-shelf approach to robot design. In some narrow sense Bellingham is a younger version of Webb himself—younger, and perhaps a bit more practical. “Webb is an engineer who loves to find novel and sexy solutions to problems,” says an oceanographer who has worked with him, meaning sexy rather than easy or obvious. Webb would just say he is an inventor.

The Labrador Sea is a stepping-stone for him. A success there, he hopes, along with the success of his thermally powered profiler, will convince skeptical oceanographers that his two ideas should be married at last. Before he retires, he would like to see thermal Slocums porpoising through the ocean—chasing eddies, cruising the meridians, and patrolling their designated stations like faithful sentinels. He would like to start the job of freeing the individual oceanographer, and our knowledge of the ocean, from the constraint of needing a ship. Most of all, he would like to prove that he and his friend were right, and a robot really could be made to cross the ocean and maybe even circle the globe. “We had a good team here, and it will be hard to get that back,” he says. “A lot of people say Slocum's a great idea—and they'd love to use it when we're finished with it. It took someone of Hank's stature to keep it going. But we'll sneak up on it yet.”


matter
antimatter
AMS
plus
minus

THE ANTI±MATTER MISSION

BY GARY TAUBES

In our tiny corner of the cosmos, no one has ever seen antimatter stars in antimatter galaxies. Yet that doesn't mean they're not out there—they could in fact make up half the universe. A few curious physicists think it's time to find out. And NASA, for reasons of its own, agrees.

Photo Illustrations by
A Fuel Project, Nad & Bor

IN THE SUMMER OF 1984, Michael Salamon and Steve Ahlen went looking for antimatter in the cosmos the old-fashioned, low-budget way. Salamon, who was then at the University of California at Berkeley, and Ahlen, who was at Indiana University, bootlegged some spare cash from a previous experiment and used it to wire up an antimatter detector—a superconducting magnet and some elaborate electronics. They rigged the contraption to sit on a shelflike structure hanging from a high-altitude balloon. The balloon was capable of rising up to 130,000 feet, where it would be above the bulk of the atmosphere and could capture unimpeded the cosmic rays that rain continuously from the heavens. After a few years building the detector and then a month of 18-hour days readying the equipment for its mission, Salamon and Ahlen launched the balloon from Prince Albert, Saskatchewan, on August 13, 1987. It rose to its heavenly altitude above the stratosphere, floated serenely for 12 hours, and then, like a dying duck, plummeted to Earth in the Canadian wilderness.

"When we finally found it," says Salamon, "it took a hell of a time to get it out. We had to bulldoze some of the forest so a helicopter could get in and fly the payload out. But then the helicopter couldn't pick it up, because the payload

THE UNIVERSE IS A BIG PLACE, COMPOSED OF SOME 2 MILLION GALACTIC SUPERCLUSTERS, AND THE ONLY ONE WE'RE SURE IS MADE OF MATTER IS OUR OWN.

had impaled itself on the trunks of trees it had knocked down. We had to disassemble the support structure." It then took Salamon and Ahlen three months to analyze the data, which came up empty in any case. They had detected no sign of cosmic antimatter. That didn't mean it wasn't there, only that their experiment wasn't sensitive enough to find it.

While Salamon and Ahlen thrashed around upper Saskatchewan, Samuel C. C. Ting was in Switzerland, establishing the largest experimental physics collaboration in the world—a $350 million, 600-physicist experiment known as L-3, which studies the collisions of elementary particles—at the European Organization for Nuclear Research, a laboratory known by its French acronym, CERN. Ting, who shared a Nobel Prize in 1976 and who has been described as the George Patton of high-energy physics, is a consummate experimentalist. But the experiment he was putting together in 1987 represented the twilight of his career, which was slowly being done in by the complex politics of the world's most expensive pursuit of pure knowledge. By 1993, Ting would be looking for a way to do one more interesting experiment, as he put it, before he retired.

So it was that one of the most renowned practitioners of "big science" teamed up with a couple of inveterate low-budget astrophysicists to go searching for antimatter. Now Ting, Ahlen, Salamon, and a few dozen collaborators have convinced NASA to conduct the most thorough antimatter search ever. The $20 million experiment will fly first on a space shuttle in April 1998 and then for three years on the International Space Station *Alpha*, beginning in 2001. It should establish once and for all whether half the universe is made of antimatter, or whether matter, the stuff we're made of, is all there is.

The search for antimatter has nothing to do with the paradox of dark matter, which is the roughly 80 percent of the universe that's obviously there but isn't emitting visible light and so cannot be seen. Ting and his collaborators are concerned instead with the 50 percent of the universe that isn't there at all—the half that should be made of antimatter. Quantum mechanics dictates that matter can arise from pure energy, that elementary particles can pop into existence from a vacuum, provided that they do so in such a way that various fundamental quantities, such as electric charge and momentum, are conserved. This happened on a large scale during the Big Bang, when the universe began, and it's been happening on a much smaller scale ever since.

ANY TIME A PARTICLE is created from nothing, the universe will simultaneously spew up its antiparticle, which will have the same mass and other characteristics but will have the opposite charge and will head off at an equal speed in the exact opposite direction. Thus protons are made with antiprotons; electrons with antielectrons, known as positrons. "The point," says Ahlen, "is that you can't make a proton without making an antiproton. That law has never been seen to be violated. So if there was a Big Bang, how can we have a universe without equal parts of antimatter as matter?"

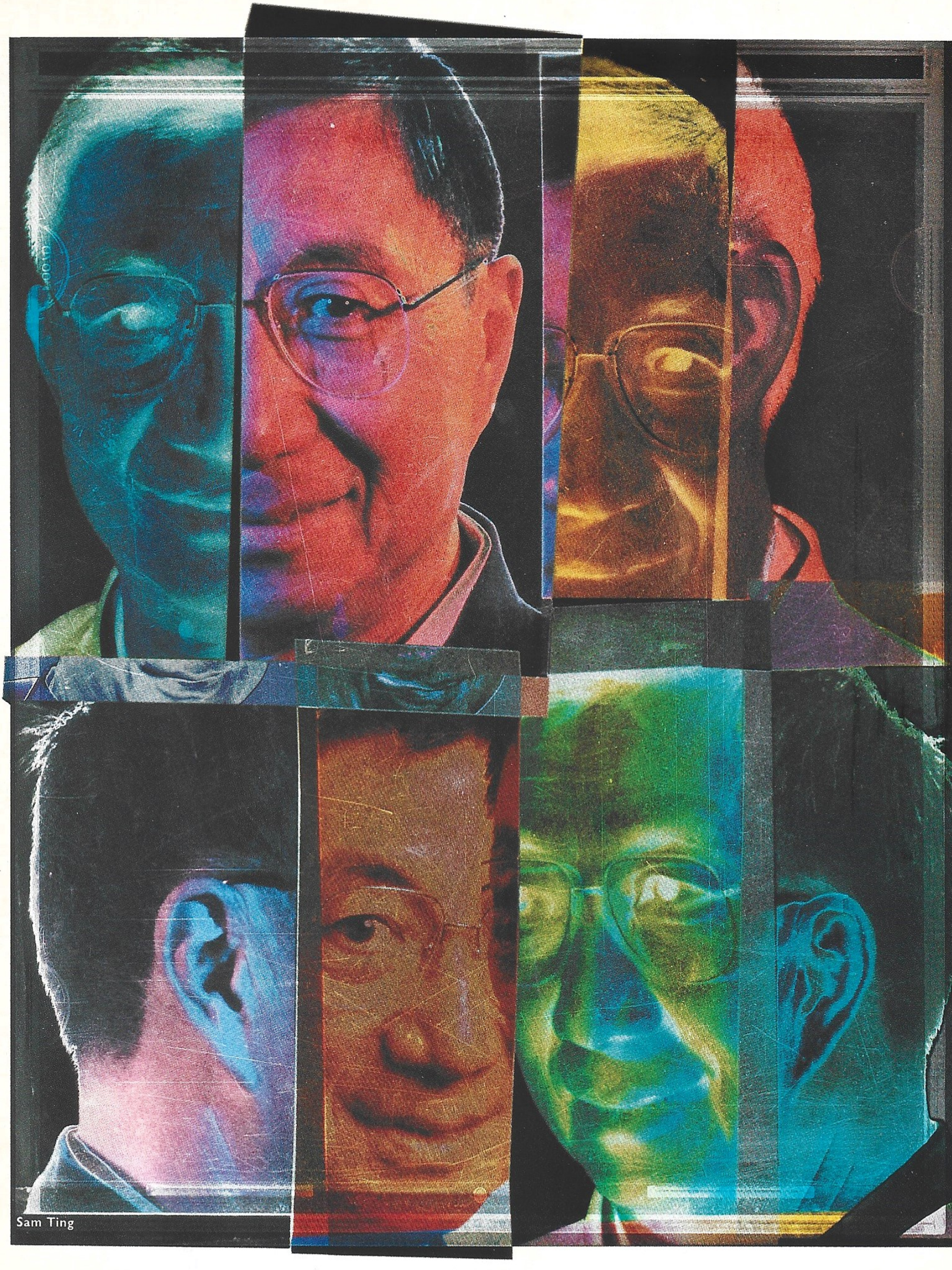
If antimatter *was* made along with matter, however, there is no sign of it. Assuming antimatter exists, one would expect chance collisions to bring it at least occasionally into contact with matter, resulting in the annihilation of both and a burst of gamma rays—very energetic photons, the packets of energy that make up light. This is another fundamental law. If matter and antimatter can be made from pure energy, then bringing the two back together again will result in pure energy. So if antimatter exists anywhere in the universe, a sure sign of its presence would be the gamma rays produced by its annihilation.

"There is certainly no antimatter in the Earth," says Ahlen, "and none in the solar system. There's none in the solar wind, because if that were different from Earth, we'd be baked in the gamma rays from annihilation. If Mars or Jupiter were antimatter, we'd see the gamma rays from that." Using similar logic, astrophysicists can establish beyond a shadow of a doubt that our galaxy, our galactic cluster, and everything up to and including at least our supercluster of galaxies—some 100 million light-years across—are made of matter and nothing *but* matter.

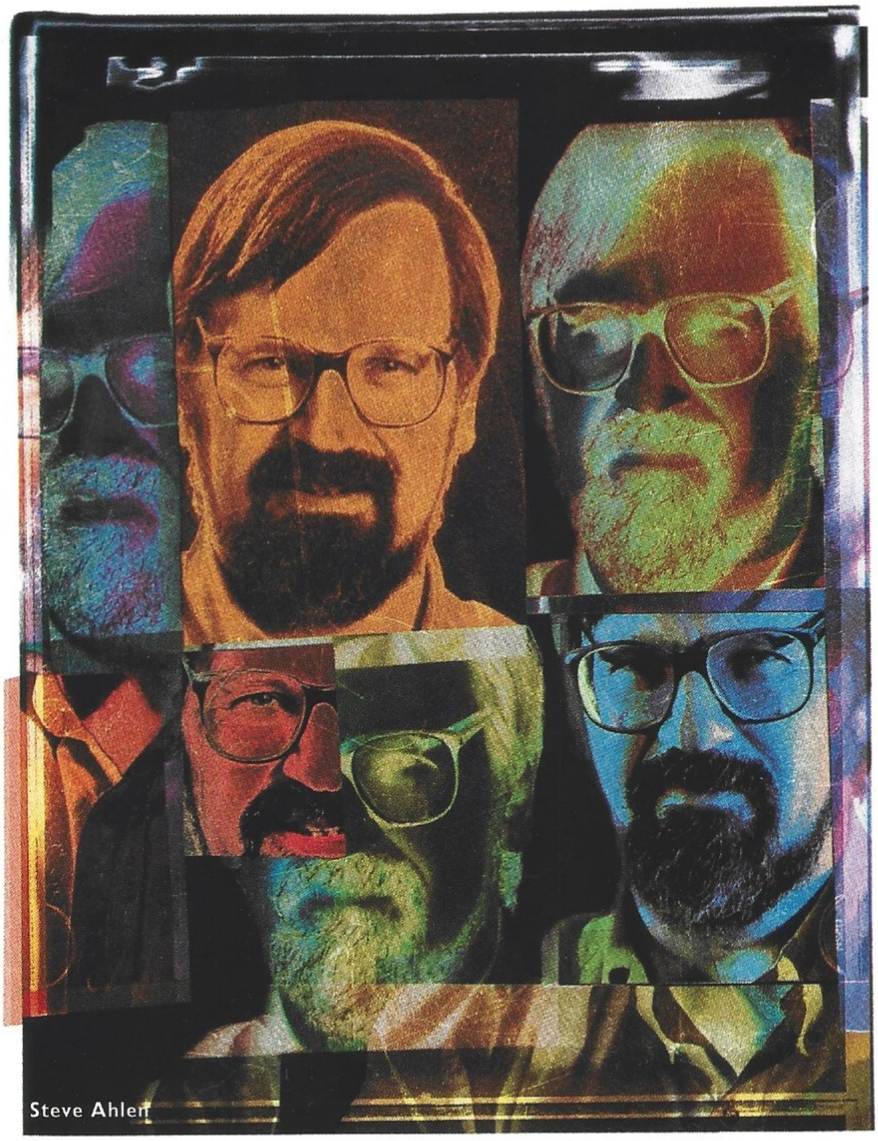
But then it gets vague. The universe is a big place, composed of some 2 million galactic superclusters, and the only one we're sure is made of matter is our own. As for the rest, that's still an open question. Because the light emitted by antimatter is no different from that emitted by matter—or rather, the antiparticle of a photon is still a photon—the only way to tell an antimatter galaxy from one of matter would be to physically examine samples of matter from the galaxy in question. This is not as crazy as it sounds. The universe is full of cosmic rays—atoms and parts of atoms that have been ejected from stars, or remnants of supernovas and other bits and pieces of stellar detritus. These cosmic rays can escape from their own galaxies and may even wander out of their superclusters and find their way to Earth. Of all the cosmic rays bombarding Earth day in and day out, astrophysicists assume a small percentage may have traveled more than 100 million light-years to get here. And those might even be made of antimatter, proving that the galaxies they came from were made of antimatter as well.

Over the years some physicists have looked for such anticosmic rays. Notable among them was the Nobel laureate Luis Alvarez, who lofted antimatter detectors in high-altitude balloons in the 1960s and 1970s. These searches found a handful of antiprotons, but nothing more. The antiprotons say little about the missing antimatter, though. True, they *could* be the nuclei of antihydrogen, but antiprotons

Original portraits by Rick Friedman



Sam Ting



Steve Ahlen

can also be made when regular cosmic rays collide with dust and debris in the interstellar medium. Heavier nuclei, such as those of anticarbon or antioxygen, could only be made by antistars and thus must be evidence of antigalaxies. But there was no sign of such antinuclei in the 40,000 cosmic rays Alvarez and his collaborators collected.

Since Alvarez last looked for antimatter, however, some new knowledge has been gathered that leaves the question of antimatter wide open. More recent calculations suggest that of all the cosmic rays crashing into Earth's atmosphere, only one in every 100,000, or even one in a million, might be from beyond the galaxy. In that case, all of Alvarez's 40,000 cosmic rays probably originated right here in our own galaxy. And if Alvarez never saw a cosmic ray from outside the galaxy, then there is no evidence that the universe doesn't have its fair share of extragalactic antimatter. There might still be antisuperclusters out there, full of antigalaxies, lit by the light of antistars.

Then again, there might not. Theorists, says Ahlen, "will tell you antimatter is the most ridiculous thing in the world to look for because everyone knows there is none." The theorists will say that considering no antimatter has been seen to date, the idea that it's out there is either "impossible" or "almost impossible." They can't imagine a scenario that would explain how antimatter could be separated from matter on a large scale (into superclusters and antisuperclusters) but not on a smaller scale (into clusters and anticlusters, say, or galaxies and antigalaxies).

According to scenarios theorists *can* imagine, the universe originated in a cosmic fluctuation, in which pure energy condensed into matter. Sometime around 10^{-34} second after time zero, a soup of elementary particles and antiparticles condensed out of this energized void, like water droplets condensing out of humid air as the temperature falls. These particles and antiparticles then began annihilating, so the theory goes, until only one in a billion was left, and that happened to be matter rather than antimatter.

Perhaps the universe began with this one-part-in-a-billion excess of matter over antimatter, and what's left over from the furious annihilation is our universe; in that case the world violated a few quantum laws when it was young. Perhaps, as the great Russian physicist Andrey Sakharov proposed in 1967, the laws of physics are out of balance, slightly favoring the existence of matter over antimatter for some reason. That lack of symmetry, known as CP violation, says that particles and antiparticles can decay differently. But CP violation, which has been measured in the laboratory, doesn't seem sufficiently unbalanced to account for the antimatter paradox. David Schramm, a cosmologist at the University of Chicago, describes the situation this way: "The intuition of most theorists is that no antimatter is there. This means if you find it, it's a great discovery and proves all these theorists wrong. But most likely it means you won't find it."

There are two ways to deal with such a situation, as Sam Ting likes to point out. Ting divides experimental physicists into two kinds: those who let theorists tell them what to do, and those who follow their own demons. "I am of the second kind," he has said. "I am happy to eat Chinese dinners with theorists, but to spend your life doing what they tell you is a waste of time."

TING WAS BORN IN 1936 in Ann Arbor, Michigan, where his parents, both professors, had come for a short visit. A few months later they took him home to China, where he stayed for the next 20 years. He then went to the University of Michigan to earn degrees in mathematics and physics.

Ting won his Nobel in 1976 for the discovery of a particle that he named the J particle (other physicists delight in pointing out that *J* resembles the Chinese character for Ting, and that Ting thus rather immodestly named the particle after himself). He'd found the particle in an experiment at Brookhaven National Laboratory on Long Island, after two other labs had rejected the experiment—one lab because theorists said Ting would never find anything.

At first Ting couldn't believe he had, so he refused to announce his discovery for over a month, while he had his collaborators reanalyze the data and collect more. He went public only because physicists at the Stanford Linear Accelerator Center (SLAC) also found evidence of the same particle, which they called the psi particle; the two groups announced the discovery simultaneously on November 11, 1974. Because of his lack of faith in his own data—usually a desirable characteristic in a scientist—Ting ended up sharing the Nobel Prize with Burton Richter, the director of SLAC, and the particle is now called the J/psi, except by Ting and his collaborators, who still call it the J, and by Richter and *his* collaborators, who call it the psi/J.

In the years since, Ting's power in physics has grown with the size of the instruments and the cost. His $350 million L-3 experiment, for instance, makes use of CERN's Large Electron Positron collider, a machine that is 16 miles in circumference and cost in the neighborhood of a billion dollars. When U.S. physicists persuaded Washington to spend $5 billion (which later grew to $10 billion) for the 54-mile-around Superconducting Supercollider (SSC), Ting proposed an experiment that would have cost $800 million and kept a staff of 1,000 physicists busy. It was a prominent and controversial candidate for the SSC but was eventually rejected in favor of an American collaboration, and physicists who discuss the decision tend to mention the politics of their world.

By the time Congress killed the SSC in the fall of 1993, the number of experiments a man of Ting's stature could lead was down to two, both of them at a proposed accelerator known as the Large Hadron Collider at CERN. Ting was not involved in either of them. He says he realized that by the time that collider is finished, he will "probably be long retired." He was ready to do something completely different. And he had also become disillusioned with the process. "It's become a very political process," he explains. "Because the experiments are very large and take thousands of people, you have to be political if you're involved. But you don't have to be involved."

One month after the SSC project was buried by Congress, Ting called Steve Ahlen, who had moved on to Boston University. Ahlen had worked with Ting on his SSC proposal, and now Ting said he wanted to know everything Ahlen knew about astrophysics. The next two months constituted an intensive session of brainstorming with Ting, Ahlen, Salamon—who had moved on to the University of Utah—and four other physicists: Hans Hofer, of the Swiss Federal Institute of Technology in Zurich, and Yuri Galaktionov and Ulrich Becker of CERN, all three longtime Ting collaborators, and Alvaro De Rujula, a theorist with joint appointments at CERN and Boston University. As Ting tells it, they quickly narrowed their possible experiments to two: either build a huge mirror high in the Tibetan Himalayas to study cosmic gamma rays, or put a device in orbit to look at billions of cosmic rays—not just tens of thousands—and search for the handful that might have come from distant superclusters and be made out of antimatter.

Michael Salamon

Ting decided the antimatter search from space was the better choice, if only because it had never been done. "The great thing about Ting," says Ahlen, "is that he is guided by general principles: Is there a compelling argument why there is no antimatter? No. Has anyone looked for antimatter at the sensitivity you need to? No. Then you look for antimatter. It's as simple as that. You don't have to have a lot of complicated computation to justify looking for it. Ting's standard line is 'We're exploring the unknown.'" Or as Ting puts it, "I just thought that to be an experimentalist, you really should measure this."

Such an experiment would require doing what Alvarez, who died in 1988, had advocated for the last 20 years of his life: putting a powerful magnet in space. Any electrically charged particles passing through the magnet would curve under the influence of its magnetic field. Cosmic rays made of matter would curve one way, and cosmic rays of antimatter would curve the other. Because the particles are

> **“IS THERE A COMPELLING ARGUMENT WHY THERE IS NO ANTIMATTER? NO. HAS ANYONE LOOKED FOR IT AT THE SENSITIVITY YOU NEED? NO. THEN YOU LOOK. IT’S THAT SIMPLE.”**

moving fast, and they’ve got to curve noticeably in the course of a few feet, the job requires a very strong magnetic field. Alvarez and his colleagues had proposed numerous experiments that would put a superconducting magnet in space. At the time, superconducting technology seemed the only way to get a magnet that was both powerful enough and small enough.

But superconducting magnets come with all kinds of technological complications, which translate into exorbitant costs. For instance, the magnets have to be cooled to near absolute zero and kept there at a constant temperature. This requires elaborate refrigeration, which is especially problematic in space because as the equipment orbits around Earth, it will alternately bake in sunshine and freeze in shadow. Estimates of what it might cost to put a superconducting magnet in space came in at between $150 million and $300 million. While that was comparable to the cost of a high-energy physics experiment, it was a lot to ask for an experiment that most people bet would come up empty.

IN MARCH 1994, however, Ting was visiting China when he stopped in, he says, “by chance,” at the Institute of Electrical Engineering of the Chinese Academy of Sciences in Beijing. “I found out,” he says, “that they have been building very precise permanent magnets with a new type of material, neodymium boron iron, and I learned that 90 percent of the neodymium in the world is produced in China and that they can produce very high quality, very high field magnets. The more I talked to them, the more convinced I became that this would be a good way to build a cheap magnet and do things in space.”

As a result, says Ting, the Chinese physicists and engineers agreed to build his magnet for around $600,000—“a very small fraction of the market cost.” Moreover, flying a permanent magnet in space is a proposition equivalent in difficulty to flying a kitchen magnet in space—it just needs to be anchored to the surface of the shuttle or space station. “You don’t have to worry about a power supply,” says Ting, “or refrigeration, and you don’t have to worry about how to fix it, because it can’t break.”

The magnet is only part of the experiment, however. The physicists would have to put some kind of elementary particle detector inside it that could look at a few billion cosmic rays and notice if a handful were of antimatter, without making mistakes. “In other words,” says Salamon, “you need a large enough instrument to detect a billion cosmic ray nuclei, but even that won’t be very helpful if your instrument screws up and misidentifies every thousandth nucleus, or even every millionth or every hundred millionth, as an antinucleus.”

Fortunately, Ting has plenty of experience in the particle identification business. Ting’s experiment at CERN, for instance, looks at billions of collisions between electrons and positrons and then has to sift carefully through the remains and precisely identify each particle created. To do so it makes use of silicon sensors that were designed for L-3 by Roberto Battiston and his collaborators from the University of Perugia and the Italian National Nuclear Physics Institute. Ting and his collaborators have decided to put similar technology to work inside their permanent magnet.

Picture the magnet as a vertical cylinder about a yard in diameter and a little less than a yard in height, explains Maurice Bourquin of the University of Geneva, whose group designed the detector for the antimatter search. At top and bottom are two pairs of planes made of a plastic material called scintillator, which will measure the charge of any particles entering the magnet’s hollow core, though they won’t tell whether that charge is positive or negative. The scintillator planes will also measure each particle’s speed and energy.

Crossing the magnet’s core horizontally are six planes of silicon sensors. When a charged particle passes through the silicon, it releases electrons, and their position is recorded electronically. With six planes, every cosmic ray that passes through will leave behind six hits, tracing out a trajectory through the core. The magnetic field, which cuts straight across the hollow core of the magnet, parallel to the planes of the silicon sensors, will pull particles one way or the other, so that the trajectory will be curved. From the amount of curvature, the physicists can tell how heavy the particle was. From the direction of the curvature, they can tell whether it had a positive or negative charge, which means matter or antimatter. And then, says Salamon, “if we were to detect a cosmic ray with a nuclear charge of −6, for example, which is anticarbon, this would conclusively demonstrate the existence of antistars, since carbon—or anticarbon—is produced only by stars, in a process called nucleosynthesis.”

The catch is that the cosmic rays are likely to curve no more than 100 microns—one-tenth of a millimeter—as they pass from one end of the magnet to the other. So Ting, Battiston, and company have to make sure they can detect the position of each “hit” with an accuracy of a few microns, or they might mistake a cosmic ray curving in one direction for one curving in the other. Battiston says that they can build the silicon sensors so they can identify the point at which a cosmic ray passed through to within 10 microns. They’ve also come up with a way to build the sensors so that they will keep that accuracy even through the trauma of a shuttle launch. Among other things, the silicon sensors will be bracketed by thin sheets of carbon fiber, which will keep them rigid during launch. The fibers won’t blow the sensors’ accuracy by expanding or contracting, no matter how the temperature may vary—from 72 degrees in Geneva, for instance, to 3 degrees above absolute zero in space. Once the detector is in space, the researchers figure, they can double-check the accuracy of the sensors by using extremely high energy cosmic rays that will pass virtually straight, even through the high magnetic fields of their experiment.

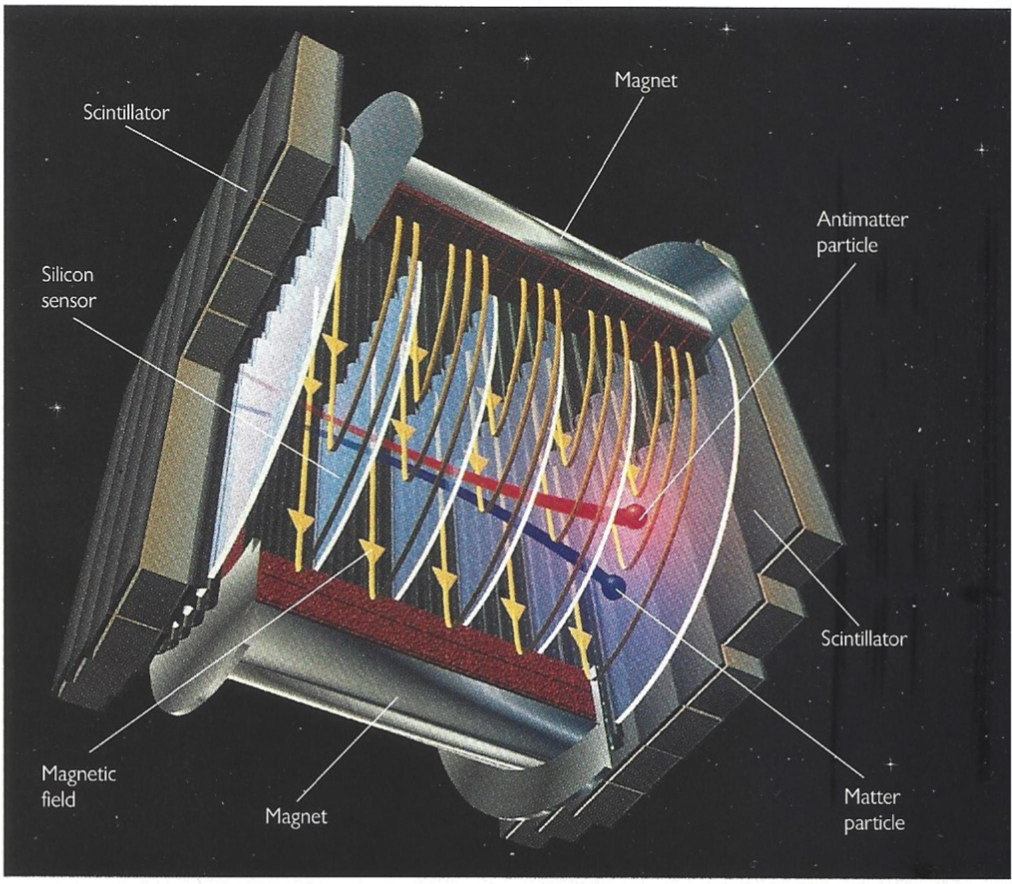
Having an experiment that will work in space, however, is not the same as getting it there. Although the AntiMatter Spectrometer (AMS), as Ting and company were calling their experiment, could fly as a satellite, both NASA and the European Space Agency had such lengthy procedures for approving satellite programs, and such backlogs in launching satellites, that they "wouldn't be able to put it up before 2017," says Bourquin.

International Space Station *Alpha* looked like a better bet. The project had begun life as the $80 billion U.S. Space Station *Freedom*, but in 1993 President Clinton internationalized it. For years the scientific community had fought against the space station, calling it an extraordinarily expensive public relations scheme. If *Freedom* had a constituency, scientists argued, it may have been the aerospace industry, but it certainly wasn't scientists. By 1992 some two dozen scientific societies, from astronomers to cell biologists, officially opposed the project.

"I can see NASA," says Bourquin, "with this big remodeled *Freedom* project, really needing some science. Now, what kind of good science could be put up there? Maybe a lot of little biology experiments—mice or whatever running around—but what about a big science experiment?"

Ting's project looked like the answer. He wasn't just offering NASA big-time science for the space station, he was offering big-time science at a bargain rate. With his huge international collaboration, drawing on the engineering skills of a dozen nations, Ting could promise to build the experiment for perhaps $20 million. The Department of Energy would peer-review the experiment, making sure it was scientifically worthy, and then ante up $3 million, and Ting's foreign collaborators would contribute the rest. All NASA had to do was fly the AMS first on the space shuttle—"Sam wanted the chance to fly it once," says Dan Goldin, the head of NASA. "He would check it out, bring it back to the ground, and retune it"—and then put it back up on the space station. "It costs us all of $13 million to take it up and down twice and attach it to the space station," says Goldin. "For a very small amount of money we have the potential for blockbuster science."

In return, NASA and Goldin required that Ting and his colleagues abide by their safety regulations and requested that Ting change the name of the experiment to the Alpha Magnetic Spectrometer. The new name avoided the implication that the only science AMS could do would be a search for antimatter. After all, says Ahlen, "if you talk to people in hallways, they'll tell you everyone knows there is no antimatter." On the other hand, those same theorists will say that certain particles that are hypothetical candidates for the dark matter problem—that's the 80 percent of the universe that can't be seen—are likely to decay into antiprotons. Ting's experiment could collect thousands of antiprotons and sift through them for evidence that they originated with dark matter. For example, if a sufficiently large percentage of those antiprotons had the same energy, that would suggest they all came from the same sort of decaying dark matter particles. It's even possible that Ting's huge magnet will capture anti–dark matter particles. There was no saying. Dave Schramm, for instance, who reviewed Ting's proposal for the Department of Energy, says he recommended the experiment not because he thought it would find antimatter but because it was an excellent bet to solve part of the dark matter problem.

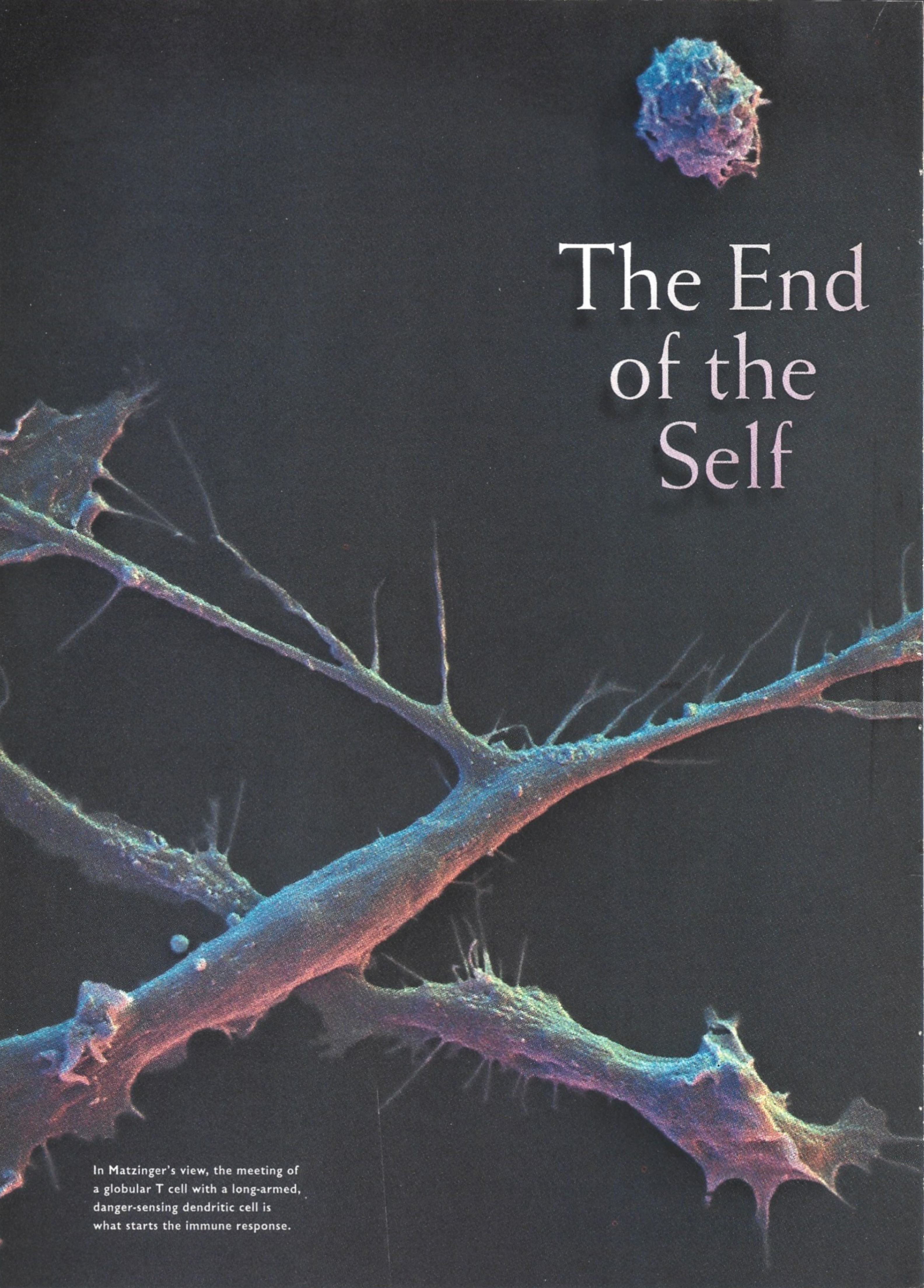


The Alpha Magnetic Spectrometer consists of a hollow cylindrical magnet with scintillators at top and bottom and six planes of silicon crossing it. When a particle enters the magnet's core, the scintillators measure its speed and energy, while the silicon sensors keep track of its trajectory. The magnetic field inside the detector pulls particles made of matter in one direction and those made of antimatter in the other.

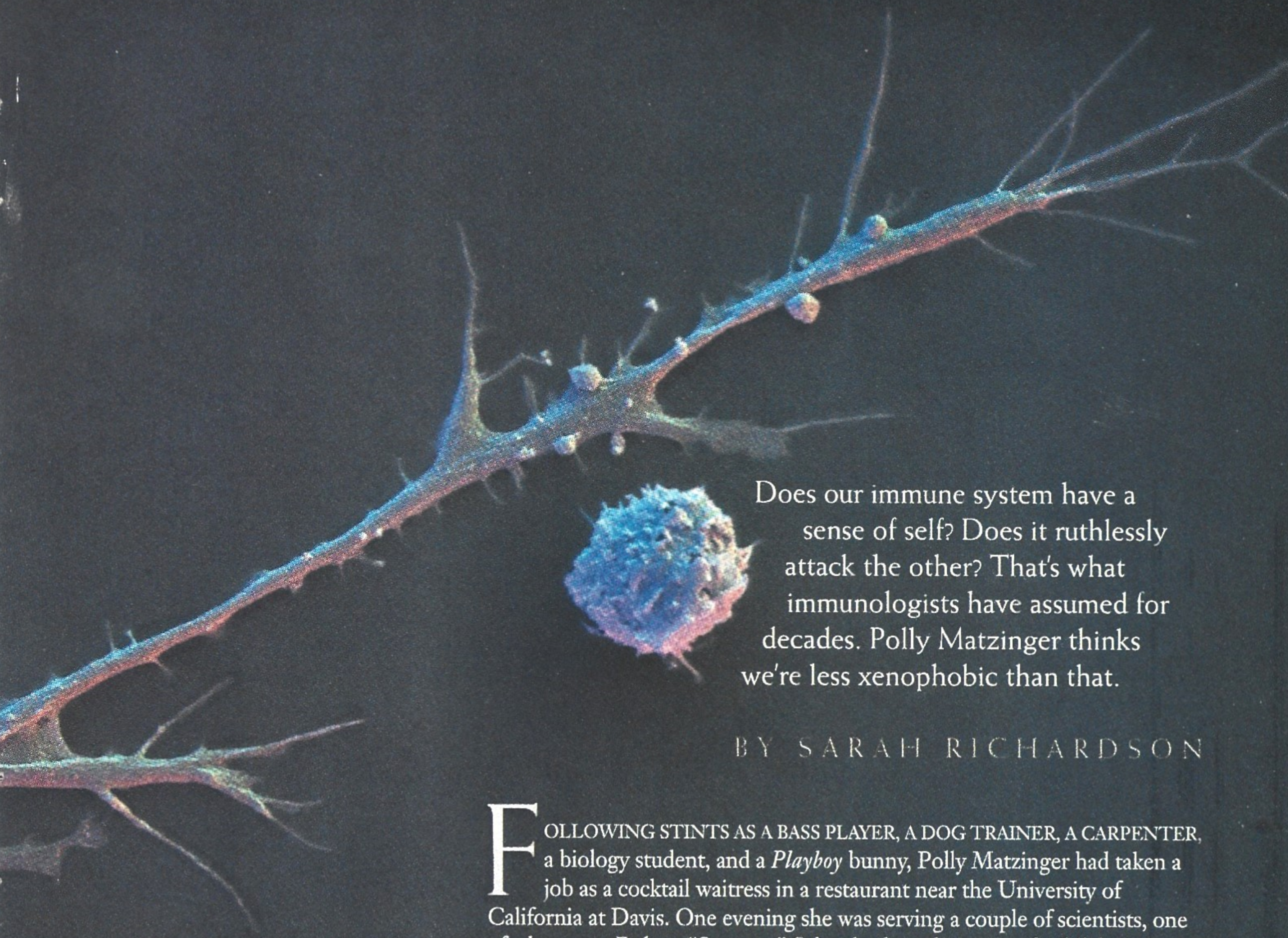
Ting doesn't seem too concerned one way or the other. In his lectures on the AMS, he likes to date the first use of precise light measurements in astronomy to 1054, the earliest exact record of a supernova, which happens to be a Chinese record. In all that time, he says, "nobody has ever done a precision measurement of charged particles in space. We're going to do that. We're going to study very clearly the composition of cosmic rays, and we will learn a lot from it. Since it's never been done before, we don't know what we're going to get. But we're going to get something." D

DANA BERRY

The End of the Self



In Matzinger's view, the meeting of a globular T cell with a long-armed, danger-sensing dendritic cell is what starts the immune response.



Photographs by David Scharf

Does our immune system have a sense of self? Does it ruthlessly attack the other? That's what immunologists have assumed for decades. Polly Matzinger thinks we're less xenophobic than that.

BY SARAH RICHARDSON

FOLLOWING STINTS AS A BASS PLAYER, A DOG TRAINER, A CARPENTER, a biology student, and a *Playboy* bunny, Polly Matzinger had taken a job as a cocktail waitress in a restaurant near the University of California at Davis. One evening she was serving a couple of scientists, one of whom was Robert "Swampy" Schwab, then chairman of wildlife and fisheries at Davis and now a professor emeritus. Schwab and his colleague were talking about a recent experiment when their waitress pointed out a few errors in their reasoning. "We said, 'Holy cow, who's that?' "

Matzinger and Schwab struck up an acquaintance. "She had a penetrating mind," says Schwab. "She could spot the problem, the picture, and half the solution. There are people who are suited for research, and you can spot them." Says Matzinger: "He started a nine-month campaign. He said, 'You're a scientist! You should be a scientist.' And I said, 'Go away—it's going to get boring, like any other job. Everything gets boring after a while.' And then he'd come back at closing time and we'd go to an all-night Denny's and talk science."

Those talks, says Matzinger, helped her decide to return to school and become a scientist. A few years later, when Schwab got wind that Matzinger was receiving funding to do immunology research, Schwab's colleague dismissed her as a charlatan. "He said, 'She's just a barmaid,' " Schwab remembers. "But I said, 'No, I think it's true. If more barmaids had minds like hers, you and I would be out of a job.' "

Nearly 20 years later, the erstwhile barmaid is now chief of an immunology lab at the National Institutes of Health, the author of dozens of scientific papers, and the creator of an award-winning film about the immune system. But she is still poking holes in the reasoning of

Polly Matzinger says our immune system hates dangerous things, not foreign ones.

scientists. In fact, Matzinger thinks there is a big hole right in the heart of immunology. For almost 50 years, immunologists have thought they understood the fundamental job of the immune system: it was to recognize the difference between self and nonself, and to defend the body against the alien. Matzinger disagrees. She says the immune system doesn't bother with a sense of self—it just has a clear sense of danger.

THE SELF/NONSELF MODEL DATES FROM the end of World War II, and some historians have argued that it—and the wide support it has enjoyed—may have been shaped by cold war xenophobia. But the man whose research laid the experimental foundations for the model was a prophet of immunologic tolerance. One day in 1944, Peter Medawar, then a zoologist at Oxford—and not yet Sir Peter the Nobel Prize winner—was sitting in his garden with his family when a Royal Air Force bomber buzzed over at low altitude and crashed a couple hundred yards down the road. A badly burned pilot was pulled from the wreckage, and the surgeon at the local hospital, a colleague of Medawar's, asked for Medawar's help in treating the victim with skin grafts.

By then it was already known that the body, though it will accept grafts of its own skin, will swiftly reject skin grafts from another person. The airman was nevertheless treated with foreign grafts, in hopes of giving his own skin a chance to grow back. Medawar and his colleague thereupon made an interesting observation: second grafts from a particular donor were rejected faster than the first ones had been, and faster than grafts from fresh donors. The implication of that observation, which Medawar went on to confirm with controlled experiments in rabbits, was clear: the rejection was immunologic. The airman's immune system was rejecting foreign skin as if it were a virus, and having seen it once, was remembering it the next time—just as an immune system would remember and be prepared for, say, chicken pox.

That observation didn't help the airman any (although he did recover), but it set Medawar on a course of research that not only made him an immunologist but also transformed immunology. If rejection of skin grafts was an immunologic phenomenon, it was natural to ask, as Medawar did, whether it might be possible to make the immune system more tolerant. Experiments in cattle twins had already suggested such tolerance was possible. Because cattle twins share a placenta, their blood-forming cells mingle as they develop in the womb. As a result, even fraternal cattle twins—which are not genetically identical—can accept skin grafts from each other. Somehow the early exposure to the foreign blood cells trains the immune system to accept the foreign tissue as self.

In a seminal series of experiments, Medawar showed that such tolerance could be induced artificially. He took pregnant brown mice and injected their fetuses with cells from a white mouse. When the brown offspring grew up, he grafted patches of white skin onto them. The white skin was not rejected; instead it established healthy islands of white in a sea of brown fur.

If Medawar's experiments with rabbits had suggested that the immune system distinguishes self from nonself, his experiments with mice now suggested that this sense of self, rather than being fixed in our genetic makeup, is learned while the immune system is still developing in the fetus—which is why it could be modified at that stage by exposure to foreign cells. An Australian virologist named Frank Macfarlane Burnet had predicted as much; it was he who provided the first theoretical formulation of the self/nonself model. In 1960, Medawar and Burnet shared the Nobel Prize in medicine for their pioneering work, which paved the way for transplantation biology. No organ transplants are done today without the careful matching of tissues—that is, without the matching of immunologic selves—and the administering of drugs that suppress the immune response against the foreign organ.

Background for portrait by Fran Heyl and Assoc.

PHOTOGRAPH BY KLAUS SCHÖNWIESE

The self/nonself model, however, has gotten considerably more sophisticated since Medawar and Burnet's day. Immunologists now know, for instance, that the responsibility for rejecting foreign skin grafts falls on T cells—the brokers of the immune response, which must be activated against a specific target if the response is not to grind to a halt. There is even a standard theory of what it is on foreign skin that T cells recognize as foreign: a distinctive molecular badge called MHC, for major histocompatibility complex. MHC is a set of proteins, found on the surface of nearly all body cells, whose function is to provide a window display of a cell's contents—both normal proteins and, if the cell is infected, viral ones. But because the structure of MHC itself is different from person to person, it is considered a marker for the self. Thus the immune system sees cells that bear viral proteins (displayed by their own body's MHC) as foreign. It sees skin grafts as foreign because they contain cells displaying a nonself MHC.

How do T cells learn what is self and what is nonself? The long-standing explanation is that immature T cells, which are born in the bone marrow, undergo a clever audition as they migrate from the bone marrow and pass through the thymus, a small gray gland that lies beneath the breastbone. What the T cells encounter there are protein-MHC complexes on the surface of thymus cells, and this surface decoration is pretty similar to the surfaces of most cells in the body. Maturing T cells that respond to any of those proteins, the theory goes—and there will inevitably be some, as T cells are manufactured by the bucketload—are automatically killed off. Only T cells that don't respond to self proteins will survive and migrate out into the bloodstream and around the body. There they can attack anything nonself—such as a skin graft.

Although to some extent this winnowing of T cells may go on throughout life (just as a person's psychological sense of self is always being refined), the bulk of it is thought to occur during early development. Moreover, during that formative stage, young T cells cannot be activated. That is supposedly why Medawar's newborn mice did not reject foreign blood cells. Medawar, of course, knew nothing of T cells and had only an inkling of MHC at the time he did those experiments. But his and Burnet's fundamental insight—that the immune system's job is to distinguish self from nonself, and that it learns what is self largely during fetal development—has survived largely unchallenged. Except that Polly Matzinger is now challenging it.

IN HIS AUTOBIOGRAPHY, *MEMOIR OF A* *Thinking Radish*, Medawar described the effect of the bomber crash on his development as a scientist. "I understood now," he wrote, recalling his carefree days as a young Oxford don, "how much of my time had been wasted on unimportant projects, intellectual pastimes, and reveries." Thereafter, he was to devote most of his energy to the problem of self/nonself discrimination that Burnet had described. Matzinger's career path was also indirect, though it required something less than an airplane crash to get her into immunology. After Robert Schwab pointed her back to school, she ended up a graduate student in biology at the University of California at San Diego. To fulfill her Ph.D. requirements, Matzinger had to design an experiment, and she was looking for an idea to work on. One day in 1976 she was playing chess with a friend, Salk Institute immunologist Rodney Langman, when he suggested she explore how it is that—as had then just been discovered—T cells become so selective in what they respond to. "It was in the middle of an argument with Rod," Matzinger remembers, "that I had my first creative scientific thought."

But the more Matzinger learned about the theoretical foundation for her chosen field, the more dissatisfied she became. "Change is a hallmark of life," she says, "and yet models based on self/nonself discrimination didn't seem to explain why our immune systems don't kill us off when our body changes. What happens when we go through puberty? When a woman who was never breast-fed as a baby has her first child and starts lactating, why isn't the lactating breast rejected?" Nor were changes in the body the only thing the self/nonself model had trouble accommodating. Why, for instance, don't mature T cells routinely attack proteins they're never exposed to in the thymus, such as the ones on cells in the skin, brain, and liver?

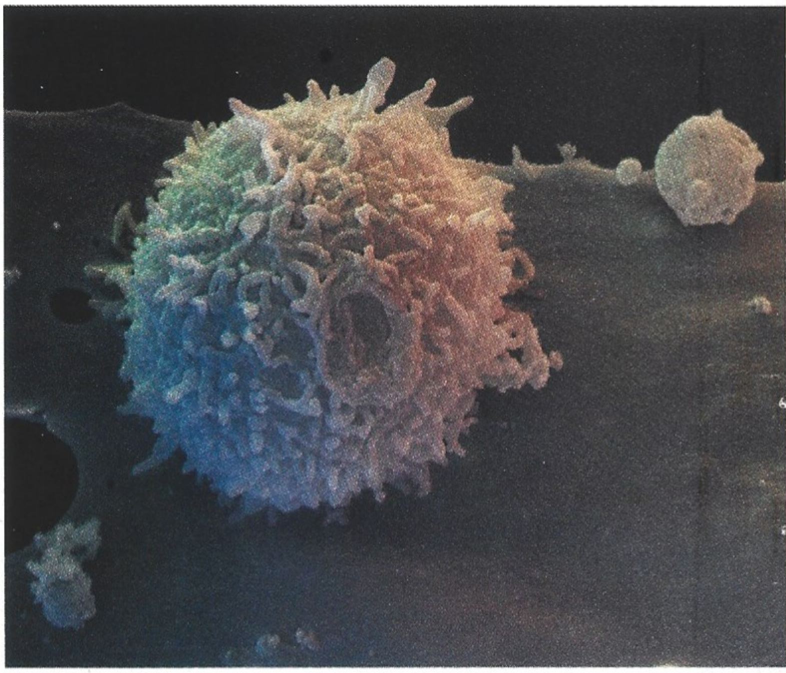
Some researchers had already developed the germ of an answer. It takes more to activate a T cell, they hypothe-

A dendritic cell can turn on T cells. It may also detect a cell's premature death.

sized, than binding to a protein it recognizes on the surface of another cell. Somehow—and researchers differed on the details—it won't get activated unless it also receives a second signal. The second signal might come from molecules secreted or borne by the same cell, or it might come from a different cell. Regardless of the mechanism, the cornerstone of this model is that only when that second signal is present will the T cell multiply and begin to attack.

Conversely, any time a T cell gets the first signal but not the second, it will be inactivated. This is how potentially self-attacking T cells get winnowed out in the thymus, but the winnowing continues with T cells that make it out of the thymus. As T cells circulate through the bloodstream, they are exposed to proteins they never saw in the thymus, on the surface of skin cells, say. When they bind to such proteins in the absence of the second signal, they die. But if they do get the second signal, they are activated and head for a lymph node—the fire stations of the immune system—and activate other immune cells.

The immune system is a lax border guard: mothers don't reject fetuses.



But what is the nature of the second signal? There has never been a good answer. The current consensus, though, is that it comes from a class of cells called antigen-presenting cells, or APCs. An antigen is a molecule that an immune cell can bind to, and antigen-presenting cells include macrophages and dendritic cells. Macrophages are scavenger cells; they migrate through tissue, eating up dead cells—but also bacteria, bits of which they display on their surface, where T cells can detect them. Dendritic cells are the most recently discovered APCs and still the most mysterious. Thought to be our bulwark against viral infection, they are scattered about in the lymph tissue, as well as throughout the other tissues of the body.

The APCs produce some kind of molecule on their surface that can activate T cells: that is the second signal. When a T cell binds to such an APC, the T cell multiplies and launches an attack on cells that display the telltale protein-MHC complex—cells infected by a virus, foreign skin cells, or whatever. For a brief period, activated T cells can kill those cells without additional stimulation; then they will quiet down. But as long as the virus is being made—and is activating APCs—these T cells will continue to be reactivated. Ultimately, after the virus is eliminated, virus-specific T cells will quiet down, and these cells linger as "memory" cells. They require additional provocation to kill again but will do so much faster the next time they encounter the same pathogen—or as Medawar observed, the same foreign skin.

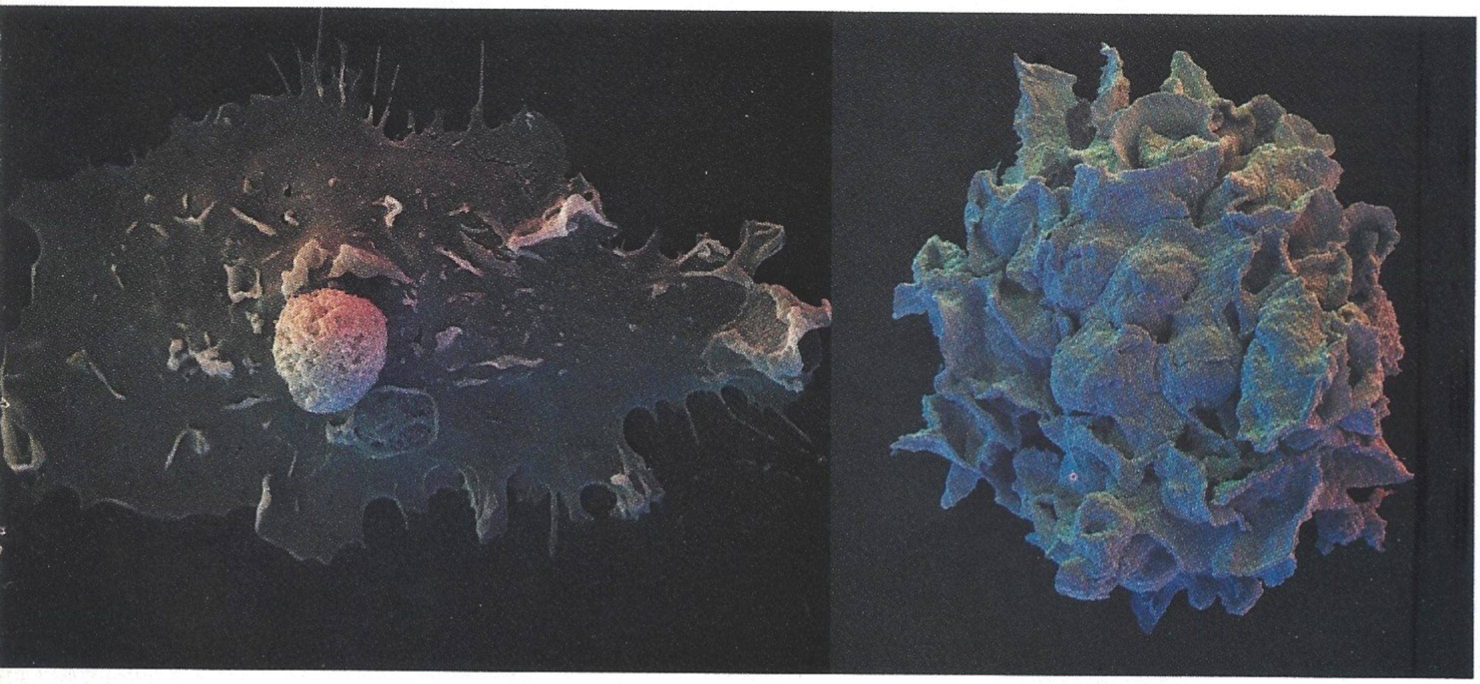
The two-signal idea sounds neat enough. But as Matzinger points out, it begs an important question: How exactly do APCs avoid launching an autoimmune response? Unlike T cells, they haven't gone through a winnowing process; they can't tell which antigens are self and which are nonself. Macrophages, for example, are constantly gobbling up dead tissue cells. If they were thereupon to activate T cells, we'd face a continual immune assault on our own tissues. "That's been a major sticking point for 20 years," says Matzinger. "If APCs can't discriminate between self and nonself, then they couldn't be the cells that control the immune response." On the other hand, if you've concluded that telling self from nonself isn't what the immune system does, then the indiscriminate nature of APCs is no problem at all.

MATZINGER DID NOT COME TO THAT conclusion at the outset of her career. For a while, as she gradually became absorbed into the immunologic establishment, she buried her doubts about the self/nonself model. Then in 1989, a young scientist named Ephraim Fuchs came to work as a postdoc in a neighboring National Institutes of Health lab. Fuchs, now an oncologist at Johns Hopkins, had the same initial doubts that had worried Matzinger a decade earlier. "By then I had my old-fogy glasses on," Matzinger recalls. "But here was an intelligent, highly trained person, and he was having the same problems with the model that I had had. He didn't think the immune system could discriminate between self and nonself. And he reawakened it all."

Fuchs reminded Matzinger of all the evidence indicating that if the immune system is designed to keep out foreigners, it is a rather lax border guard. Mothers don't reject fetuses, not to mention their own lactating breasts; none of us attack the food we eat, rife with foreign antigens as it is; nor do we reject the millions of bacterial organisms that colonize our gut. Indeed, some of those bugs make the vitamin K that helps our blood clot. In general, Fuchs argued, infection is not always a bad thing; a virus, for instance, might provide us with helpful genes we would otherwise never acquire. In the long march of evolution, an immune system that took a wait-and-see attitude might be more advantageous than one that summarily evicted all invaders.

Which left Matzinger and Fuchs to ponder this question: If the immune system doesn't discriminate between self and nonself, what does it do? "And that's when we came up with the idea that an immune system that discriminates dangerous from nondangerous would be much more sensible than a system that discriminates self from nonself," Matzinger recalls. "The only thing left to do then was to figure out how it could do that."

The answer came to Matzinger in the bathtub one day. A natural way for the immune system to detect danger, she realized, would be for it to detect when tissue cells somewhere in the body were being subjected to horrible deaths. Cell murder is different from normal cell death. When a cell dies normally, it shrivels up and displays signals that invite a macrophage to eat it. The dead cell's contents are never released into the extracellular environment. But when cells are infected or otherwise killed, they leak, spilling their insides all over the place. One could hardly ask for a better signal that the body was under attack.



A T cell (left) can get orders to kill from a dendritic cell (center, background) or a macrophage (right), the "big eater" scavenger cell of the immune system.

Now all Matzinger needed was some kind of sentry that could detect that alarm. The answer came while Matzinger—who still trains prizewinning border collies—was working with one of her dogs. During a break in a training session, Matzinger sat down and watched her pupil curl up with its nose under its tail and go to sleep. She thought: "I need a sheepdog that can wake up when wolves attack and the sheep"—the injured cells—"start bleating." Dendritic cells, the least-known type of antigen presenters, were tailor-made for this role of immune sentry. All tissues are laced with them; their long, fingerlike extensions—the dendrites—reach into every cranny of the body, forming a lacy network. Under normal conditions they rest quietly. But when dendritic cells are activated by whatever it is that activates them, they get moving: they literally crawl through the tissue. And their typical destination is a lymph node.

Soon the whole thing seemed clear to Matzinger. Maybe what activates dendritic cells, she thought, is danger—danger as signaled by prematurely dying cells floating around the tissue. Maybe they provide the signal that prompts dendritic cells to sound the alarm. The scenario wasn't hard to imagine. Somewhere in a piece of tissue, a cell dies a nasty death—perhaps it is a skin cell burst open by a chicken pox infection. Viral proteins and skin proteins both spill out of the cell. A nearby dendritic cell, sensing the danger, somehow becomes activated and begins drinking up the dying cell's contents. Then it starts crawling toward the nearest lymph node.

There, like a good APC, the dendritic cell presents antigen—it displays viral proteins and skin proteins on its surface. The T cells that can recognize the telltale proteins bind to them, thus getting the first signal. But along the way to the lymph node, prompted somehow by the evidence of cell death it has absorbed, the dendritic cell has produced another substance on its surface, one of a group of molecules whose identity is still being worked out. That substance gives T cells the second signal: it tells them to get going. Multiplying rapidly, they fan out in search of virus-infected cells to kill. Eventually they eliminate the virus. A few of them remain as memory cells to respond more quickly the next time it invades.

In this scenario, Matzinger realized, the immune response would inevitably cause collateral damage. Some of the T cells—the ones that happened to bind to skin proteins on the surface of the dendritic cell rather than to chicken pox proteins—don't head for infected tissue; they simply head for skin. They even kill a few perfectly healthy skin cells—but then they "rest down." In this state they can't kill unless restimulated with both the first and second signals. As long as the infection continues, they are likely to become reactivated. But once the infection is cleared, they rest down. When they bind in this condition to skin protein, they receive signal one without signal two. That kills them.

T cells also die in the self/nonself model when they get only signal one, and that's how self-attacking ones are eliminated. The difference between that model and Matzinger's lies in where and when the elimination takes place. In the self model the bulk of it happens in the thymus early in life. In the danger model it happens all the time. Whenever T cells bind to a protein in tissue but don't get signal two—whenever there is no danger—they die. Because our tissues provide a large and continuous source of signal one, this dying off goes on continuously throughout life, as T cells circulate through the bloodstream and lymph nodes. Says Matzinger: "We are constantly acquiring tolerance to our own proteins." The self, in other words, is constantly being defined anew—which is another way of saying that it doesn't really exist at all.

SAYING THAT THE IMMUNE SYSTEM REsponds only to real danger provides a natural explanation for why it doesn't attack fetuses, gut bacteria, or other useful things that it ought to consider nonself: those things aren't dangerous, they don't burst cells, and they don't activate dendritic cells. But why does it sometimes attack things it ought to consider nondangerous? Why does autoimmune disease occur? Matzinger has an answer, albeit a speculative one. The conventional view is that an autoimmune disease arises from a mistake of the immune system—essentially from a poorly developed sense of self. But Matzinger thinks there are several ways in which patients without defects in their immune response may suffer autoimmune disease.

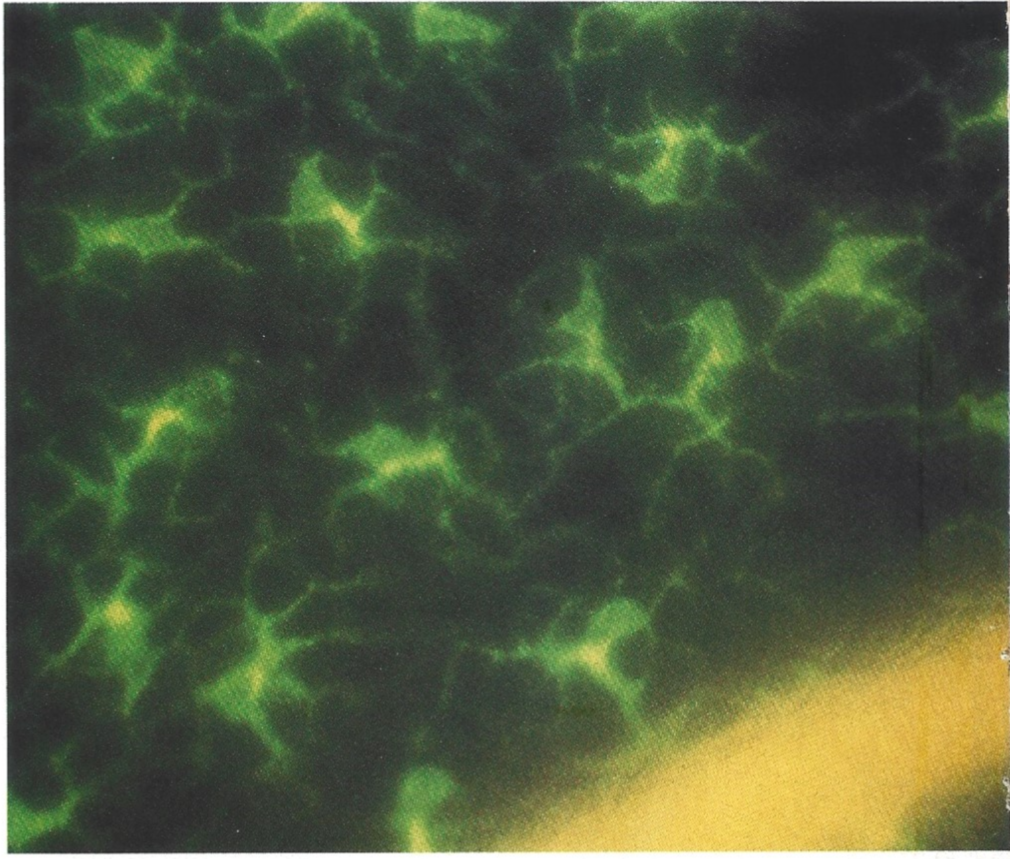
One possibility is that the real culprit is a hard-to-detect, slow-growing infection. Patients with rheumatoid arthritis and multiple sclerosis often suffer intermittent flare-ups; these may be the result of a viral infection in which T cells are activated against normal body proteins. When the infection is cleared, the autoimmune response dies down. Another possibility is that a stretch of a person's MHC may bear an unfortunate resemblance to a viral protein. Thus, a bout with a virus could activate an ongoing T cell response to a person's MHC. In either case, the immune system is responding to real danger signals. Yet another possibility is that the tissues themselves are provoking the ongoing immune response—perhaps because of some genetic defect that causes abnormal cell stress or death. Matzinger notes that a defect in the gene that regulates normal cell death causes lupus in mice.

What about organ transplants? Why are they so often rejected? "Some have objected that my model can't work," says Matzinger, "because a transplanted liver isn't dangerous. But what happens when organs are transplanted? They get cut up and reattached." All that surgery causes injury. The dendritic cells in the donor organ start heading for the lymph nodes. There they bind to recipient T cells that have never seen the donor organ's brand of MHC. The T cells get activated and start attacking the donor organ.

Indeed, Matzinger's theory can explain experimental results in transplantation that have been puzzling immunologists for nearly 20 years. In the early 1970s, a couple of researchers had succeeded in grafting tissue from one mouse into an unrelated mouse without using immunosuppressive drugs. Why did it work? Before grafting, the donor tissue had been depleted of "passenger leukocytes," the cells that some thought aroused the host immune response. Researchers now know that those cells were actually dendritic cells—which were first isolated in 1973 by Rockefeller University researchers Ralph Steinman and Zanvil Cohn.

Even more impressive is how Matzinger can reinterpret the pioneering experiments by Medawar. The reason Medawar's bomber pilot and later his rabbits rejected their skin grafts, she explains, was not simply because the skin graft was foreign but because it contained activated dendritic cells. The skin is laced with them. "If you take a piece of skin and put it in a culture dish," says Matzinger, "just the bruising that is created by the incisions is enough to activate the local dendritic cells, and they will do what they do, which is to leave. In fact, that's a nice way of purifying them, because they crawl out into your petri dish."

Conversely, says Matzinger, the reason Medawar's newborn brown mice didn't reject the white-mouse blood cells he injected into them was not that their sense of self was still malleable: it was that the injection didn't give them a clear danger signal, because it didn't contain enough activated dendritic cells to arouse a newborn mouse's small supply of T cells. What it did contain was stem cells—the cells that give rise to all types of blood cells—which took up residence in the bone marrow of the brown mice, giving them a lifelong supply of white-mouse blood. The newborn brown mice became tolerant of that blood and of the MHC it displayed in the same way they became tolerant of their own MHC—any maturing T cells that could respond to it got signal one without signal two, and promptly died. By the time Medawar grafted white skin onto them—thus providing them with large amounts of signal two, in the form of activated dendritic cells—there were no T cells around that

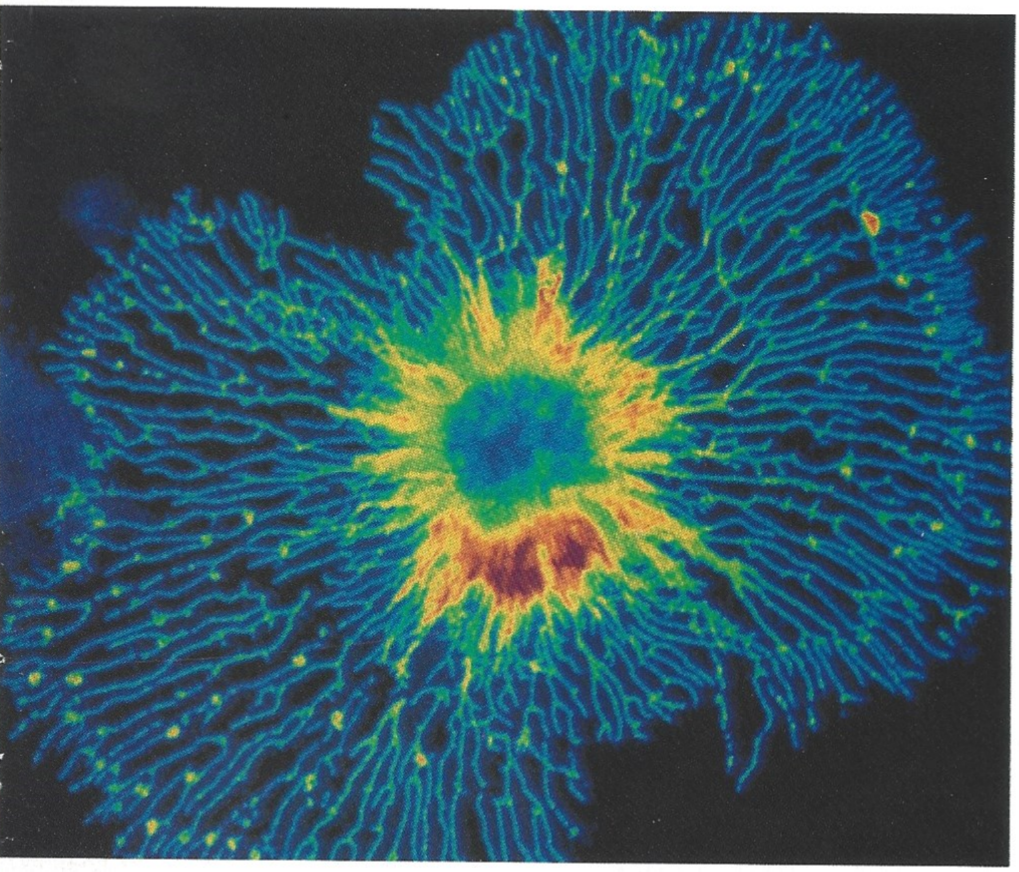


A many-armed dendritic cell (opposite) and a lacy, many-celled network (above).

Courtesy Ralph Steinman

could respond to it. So the mice tolerated the graft.

But that tolerance, Matzinger stresses, was not something they learned as newborns. Recently she, Fuchs, and their colleague John Ridge showed as much: they repeated Medawar's experiment. But instead of injecting foreign blood cells into newborn mice, as Medawar had done, they injected activated foreign dendritic cells—far more than Medawar's original injection had contained. If the self/nonself model were true, the change shouldn't have made a difference; any foreign cells should have been tolerated, if administered early enough, when the mice were still developing their sense of self. But that's not what happened. Matzinger's mice rejected the dendritic cells. "The experiment shows that the immune systems of the newborn mice are not inherently tolerant," she says. "They can respond to danger."



Jean Davoust

DOES IT MAKE ANY PRACTICAL DIFFERence whether Polly Matzinger is right instead of Peter Medawar? It may. One area that could be affected is transplantation biology, the very field that motivated Medawar. Current transplantation procedures, derived from the self/nonself model, require surgeons to carefully match the donor's MHC to the recipient's and to suppress the immune response with powerful drugs. But if the activation of the dendritic cells can be controlled, it may one day be possible to transplant organs without as much fuss about who the donor is, and without subjecting patients to risky drugs.

One way might be to deplete the donor organ of dendritic cells before transplantation—although that would be difficult, because dendritic cells tend to be buried deep within the tissue. Another solution may be to create antibodies that can bind to dendritic cells and prevent them from activating T cells in the recipient. Some studies have already shown that such antibodies can block the immune response—and promote long-term tolerance—in animals receiving transplanted tissue.

The danger model may also have implications for cancer therapy. The immune system is notoriously blind to cancer cells, and the reason, as Matzinger sees it, is that tumor growth doesn't injure tissue. But cancerous growth might be controlled by repeatedly injuring cancerous tissue, thus continually reawakening an immune response. In fact, researchers are currently developing a cancer vaccine that contains heat shock proteins—substances a cell produces whenever it is stressed. By injecting heat shock proteins into tumors, they hope to stimulate an ongoing immune response against the tumor.

Not surprisingly, though, considering that Matzinger is going up against a theory that has been entrenched for half a century, the reaction to her danger model has been mixed. Transplantation biologists and surgeons, she says, generally give it good notices. A strong supporter, for instance, is Kevin Lafferty, now director of the John Curtin Medical School of Research in Australia. Lafferty was one of the first to propose a two-signal model of the immune response, and he also did some of the graft experiments in mice that are so well explained by the danger theory.

"One of the major problems of immunology has been to develop a theoretical explanation for self/nonself discrimination," Lafferty says. "But maybe we've been going down the wrong path—if things don't fit, it's time to change the metaphor. I think we're at that stage in immunology, and I think that's where Polly's been very valuable. It's going to take a while, though. People aren't going to swallow this too fast."

And indeed, a lot of immunologists aren't swallowing it, at least not whole. Some agree that the immune system may be attuned to signals of danger but point out that Matzinger has yet to do the really hard work of pinning down what those signals are. To be sure, some molecules that turn on T cells are already known, but nobody knows what substances in damaged tissue activate the dendritic cell. Others see no reason the immune system can't do both: why it can't develop a basic sense of self early in life, through the careful winnowing of T cells in the thymus, and still respond to danger later on. And still others think that the whole argument is semantic—that Matzinger has just found a different way of phrasing what the immune system does, one that doesn't change anything important. Among this last group is Rod Langman, the Salk Institute immunologist who got Matzinger into the field.

Matzinger finds the last group of critics the hardest to understand. "At least nobody is throwing rotten tomatoes," she says. "But the people who are saying, 'Well, Polly isn't saying anything new. What she's done is a very nice synthesis of everything we knew into a model that works'—they haven't really jumped off the cliff with me. They haven't said, 'What this says is that the self/nonself model is wrong.' " D

VITAL SIGNS

An Invisible Fire

BY JEREMY BROWN

DURING A SCENE IN THE MOVIE *ALIEN*, CREW members are startled to see a fist-size hole in their spaceship's ceiling, still sizzling from some substance that has just burned clear through the metal. That metal-eating stuff is, of course, the "blood" from the alien. I have met the closest thing there is to that alien's blood. It came in a small plastic bottle, and it was eating its way through my patient's hand. ■ On an otherwise ordinary evening, William Turner, a 37-year-old truck driver, noticed a paint stain on his coat. Looking for something to remove the stain, he wandered into the basement of his rented house and rummaged around. At the back of a dusty shelf stood a small bottle labeled Industrial Laundry Rust Remover. The side of the bottle carried the warning CAUTION: DO NOT USE WITHOUT GLOVES. William didn't read that bit, however, and he removed the cap from the bottle, spilled some liquid onto a rag, and began rubbing it into his stained coat. But as the stain began to fade, his right hand, the hand he was using to apply the liquid, began to hurt. After 20 minutes the pain was so intense that he had to stop. Within 40 minutes he could no longer move his fingers. Frightened and in terrible pain, he managed to drive himself to our emergency room. Fortunately, he brought the rust remover with him.

RICHARD DOWNS

William's hand looked fine, but a stealthy killer was destroying cells beneath his skin.

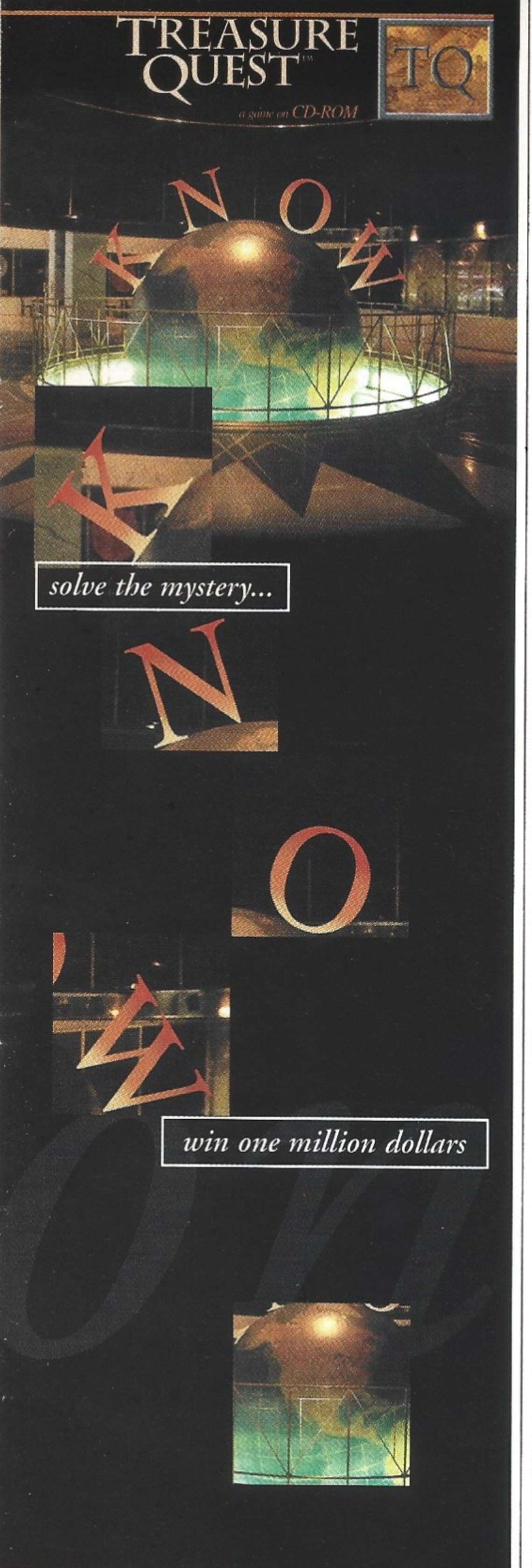
While William writhed in agony, I took a close look at his right hand. Except for some mild swelling of the fingertips, it looked just like his left hand. But if I even gently pressed on his fingernails, he grimaced and begged for a painkiller.

When we burn our skin by touching something extremely hot, it is the high temperature that kills the cells. Chemical burns are different: cells are killed by a chemical reaction on the surface of our skin. Probably the most common type of severe chemical burn comes from the sulfuric acid in a car battery. But sulfuric is not the acid to be most feared. That distinction belongs to hydrofluoric acid, a compound commonly used in solvents and rust removers, and so powerful that it can be used to etch images on glass. Although the burn it produces initially causes no blisters or changes in skin color, it can leave behind a scarred limb.

Hydrofluoric acid can severely damage the deep tissues of the body yet leave little trace of damage on the skin surface. It can even kill. People have died after a patch of skin no bigger than the sole of the foot was exposed to the substance.

Counterintuitively, perhaps, what makes hydrofluoric acid so deadly is not that it is a strong acid. In fact, compared with hydrochloric acid or sulfuric acid, it is actually weak. Acids are formed when charged hydrogen atoms bind with nonmetal atoms, and they are judged strong or weak depending on the tenacity of that bond. The weaker the acid, the less easily the bond is broken.

A charged atom, or ion, is an atom that has gained or lost one or more electrons, and it is the attraction between a hydrogen ion and a fluoride ion that creates the chemical bond in hydrofluoric acid. The bond is relatively stable because the fluoride ion—which can hold an electron more strongly than any other ion can—wants the electron that hydrogen has to offer. Yet under the right conditions, that stable bond can be broken. Because fluoride is so electron-hungry, it will latch onto chemicals that can provide electrons. And unfortunately, the tissues of the body are swarming with chemical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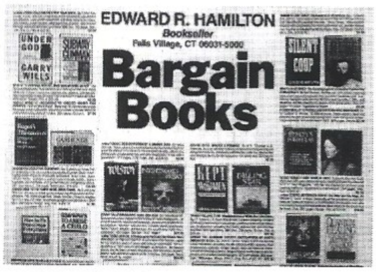
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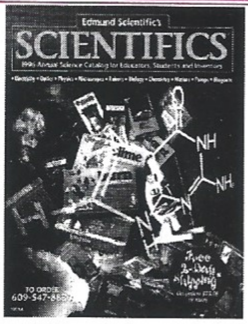
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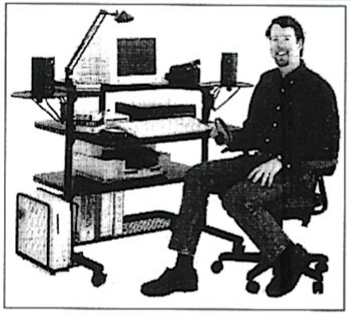

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partners that are far more attractive to fluoride than hydrogen.

To do its deadly work, hydrofluoric acid must first pass through the skin. This is easily done because hydrofluoric acid doesn't carry a charge, and uncharged molecules can easily slip through the fatty surfaces of membranes. Hand in hand, as it were, the hydrogen ion and the fluoride ion pass down through the stratum corneum, a tough, waterproof layer of dead cells. Eventually they reach living cells in the epidermis and dermis, where they meet up with a slew of new chemical partners. And that's when the terrible damage begins. The electron-hungry fluoride ion breaks free of the hydrogen ion and binds to calcium or magnesium, two electron-rich minerals. The hydrogen ion, now free of its fluoride partner, binds to enzymes that neutralize acids and keep the pH in our blood and tissue stable. This devastating disruption of the normal chemical balance—both inside and outside cells—kills cells beneath the surface of the skin.

> **I thought about what William would face if he lost the use of his hand. Saving his hand might also save his family.**

The worst damage occurs when fluoride grabs onto calcium and magnesium, minerals crucial to a host of electrochemical reactions. Without enough free calcium and magnesium, nerves fail and cell membranes collapse. The degree of damage depends on just how low the levels fall. A mild decline can cause numbness, cramps, or horrendous pain. A more severe decline can cause extreme muscle spasms, convulsions, an irregular heartbeat, and even death.

WHEN WILLIAM FIRST ARRIVED IN the emergency room, the doctors flooded his injured hand with water to wash away the hydrofluoric acid. Then they applied a gel—a mixture of calcium gluconate powder and surgical jelly. The reasoning was simple. If the tissue damage occurs because hydrofluoric acid causes dangerously low levels of calcium, then providing extra calcium to the affected tissue should prevent the damage. But William was still in excruciating pain. That meant the hydrofluoric acid was still at work deep inside the tissue. Something more had to be done. Without treatment, William could lose his hand.

Hydrofluoric acid burns are rare enough to require the advice of an expert. When I called our local poison control center, the toxicologist advised that we boost William's calcium levels by injecting calcium into his bloodstream.

There were two ways we could do this. The first was to inject calcium into a vein. Technically, this is very easy to do. The problem is that veins carry blood away from tissues, so any calcium we gave would quickly be washed away from where it was most needed. The second way was to inject calcium directly into William's radial artery, the artery in the arm that carries blood to the wrist and hand. Since arteries carry blood into the tissues, calcium injected into an artery would be most likely to reach the affected area. The problem is that arteries are much more sensitive to injections than veins. An injection of calcium into an artery could cause it to spasm, cutting off the blood supply. That was the last thing William's already damaged hand needed.

I decided to inject calcium into his vein, but I would use a variant of a technique that the toxicologist told me might decrease the blood flow out of William's arm and thus increase the delivery of calcium to the injured tissue. The technique, long used for local anesthesia, is known as a Bier's block. After placing a small needle into one of the veins in his right arm, I raised William's arm up above his head and wrapped an Ace bandage around his fingers and up his arm until I reached his elbow. The pressure of the bandage squeezed blood out of his arm. I then inflated a blood pressure cuff to a pressure high enough to prevent any more blood from leaving his arm. William now had, in effect, a right arm that was almost completely detached from the rest of his circulation. Any calcium we injected into this arm would stand a good chance of staying where it was and raising the calcium levels back to normal.

The Bier's block went according to plan. As I waited to see if the treatment eased William's pain, I thought about what he would face if he lost the use of his right hand. William was the sole breadwinner for his large family and ailing parents. Saving William's hand might also save his family.

But after nearly an hour, William felt no better. His arm looked just about the same as when I first examined it—almost normal, though very pale. But the danger of hydrofluoric acid is that the burn it causes just doesn't look like a burn at all. It was time to use the last weapon we had.

I asked the nurse who was caring for William to infuse calcium directly into his radial artery. She knew this was an unusual procedure. Although patients in the intensive care unit often have a catheter placed into the radial artery, the catheter is typically used to measure the pressure within the artery. It is rarely used to give drugs. Infusing calcium through the artery made the nurse uneasy. She worried that it would constrict, cutting off the blood supply to his hand and fingers. After I explained why we needed to do the procedure, she shrugged and made sure that I signed the patient's medical chart. That way, at least, if any problem occurred, it would be clear that she was just following the doctor's written request.

A half hour later, I returned to William's bedside. He was smiling for the first time. The throbbing sensation in his arm had eased, and although his hand remained tender, he said the pain was subsiding. Within two hours he was totally free of pain, and to prove it, he extended his right hand and gently shook my hand.

William remained under close observation until the next morning. His pain had nearly vanished, and I discontinued his calcium therapy. I checked on him the following day, just before he was discharged. He was still very sensitive to pressure on his fingertips, but there was almost no trace of the burn. Our treatment had worked. William had uncorked a flesh-eating chemical monster in a dusty bottle of rust remover but would survive unscathed.

FURTHER READING

THE FOLLOWING LITERATURE provides additional information on topics featured in DISCOVER this month:

50 Shark Therapy

Shark!: Nature's Masterpiece. R. D. Lawrence. Chapters, 1985. Biologist Lawrence, who kept a pet cat shark as a boy, tells of his many exciting encounters with sharks. From a boat or on a dive, Lawrence has seen sharks devour all kinds of prey, and occasionally they've come after him.

Science, Nonscience, and Nonsense: Approaching Environmental Literacy. Michael Zimmerman. Johns Hopkins University Press, 1995. " 'Are you lost, Daddy?' I asked tenderly. 'Shut up,' he explained." Michael Zimmerman, a biologist at the University of Wisconsin, uses this passage from a Ring Lardner short story as an epigraph to his passionately argued book. He offers critical tools for evaluating various scams, schemes, and nondisciplines—from handwriting analysis to homeopathic medicine—that he says threaten our health and environment while calling themselves scientific. He lets his readers know that "Shut up" is not an explanation.

60 A Thousand Diving Robots

Sailing Alone Around the World. Captain Joshua Slocum. Dover, 1956. It took Joshua Slocum a little over three years, starting from Boston in 1895, to become the first man to circumnavigate the globe single-handedly; one day a robotic Slocum may do it in less time. This classic book is Slocum's own gripping story of his adventures.

72 The Antimatter Mission

The First Three Minutes: A Modern View of the Origin of the Universe. Steven Weinberg. Basic Books, 1993. Writing in the 1970s, a time when the idea of the Big Bang was still blowing minds, Weinberg, the winner of the 1979 Nobel Prize in physics, made a case for an explosive beginning. This updated edition of his brief biography of the universe raises the question of that elusive antimatter.

Wrinkles in Time. George Smoot and Keay Davidson. William Morrow, 1993. Astrophysicist Smoot and science writer Davidson give a cogent and comprehensible account of scientists' efforts to detect signatures of the Big Bang. The book includes a chapter about the early antimatter searches with Luis Alvarez, on which Smoot worked.

80 The End of the Self

Memoir of a Thinking Radish: An Autobiography. Peter Medawar. Oxford University Press, 1986. In this charmingly chatty memoir, the Nobel Prize–winning biologist reflects on the scientific questions that shaped his career. Along the way, he offers snapshots of the personal and professional rivalries that forged modern biology.

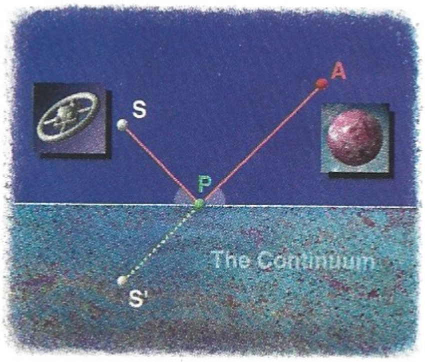
At War Within: The Double-Edged Sword of Immunity. William R. Clark. Oxford University Press, 1995. A pithy overview by a UCLA immunologist of the milestones in immunologic history and research.

Life, Death, and the Immune System. Scientific American, 1993. In this collection of concise, clear essays, immunologists illustrate the fundamentals of immune function and what goes wrong in AIDS, allergies, and autoimmune diseases.

BRAIN BOGGLERS

Solution

Suppose that the aliens aim for some point P on the edge of the Continuum. Create a reflection of S in the Continuum and call it S'. Then the distance SPA equals $S'PA$, which will be shortest when $S'PA$ is a straight line. It follows that P is the point such that SP and PA make the same angle with the edge of the Continuum.



(In the first century A.D., Hero of Alexandria used a similar argument to conclude that when light is reflected from a mirror, the angles of incidence and reflection are equal.)

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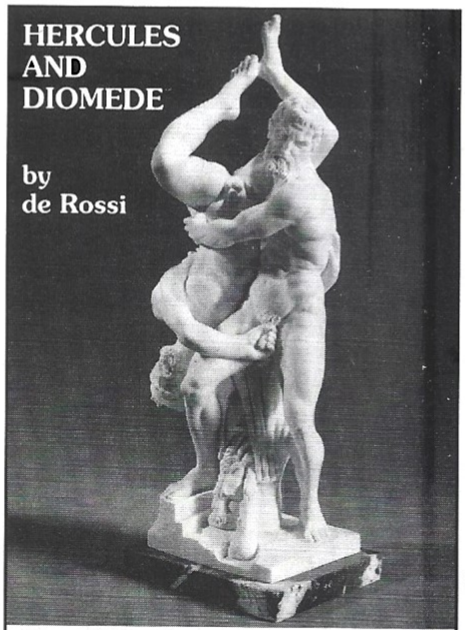

HERCULES AND DIOMEDE

by de Rossi

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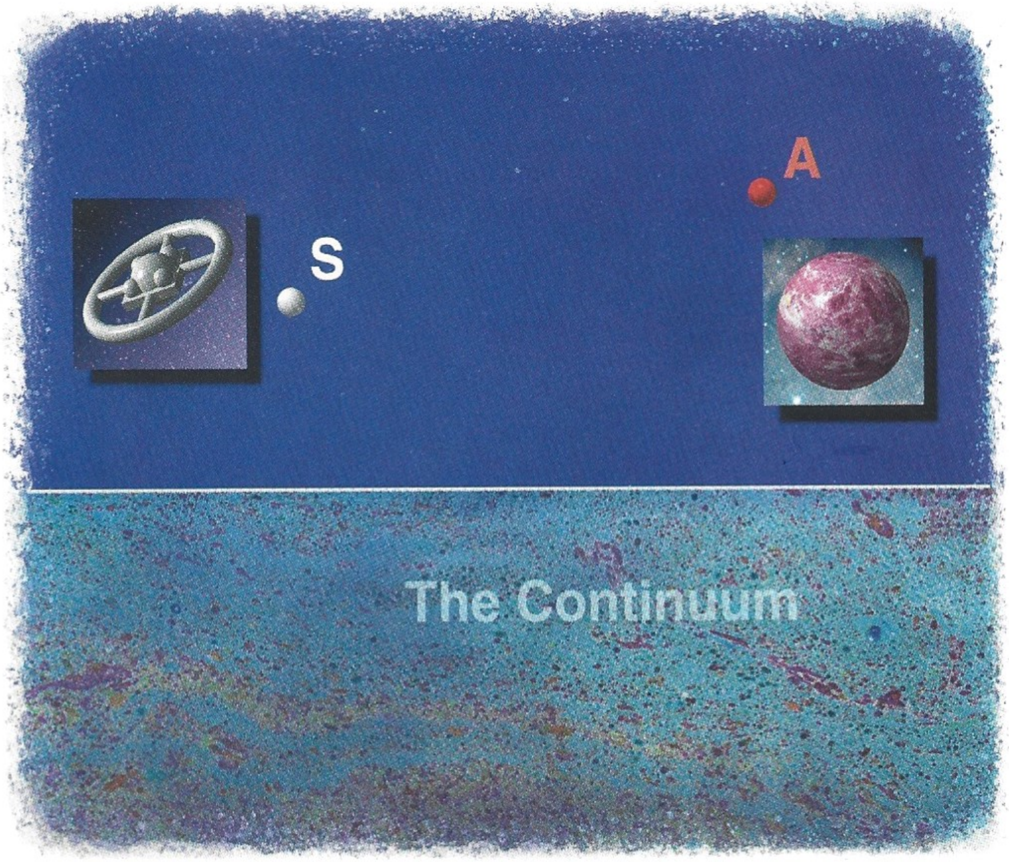
Sirius Geometry

BY CLIFFORD A. PICKOVER

Aliens from a planet circling the star Sirius have abducted a Kansas City mill worker in order to assess his intelligence. Their ship is now located at position *S* in the diagram below. The aliens wish to travel to a plasmoid wall in space called the Continuum for the purpose of refueling their ship using energy from the wall. After this they wish to travel to a star called Aleph-naught, denoted by *A*. They tell the abductee, "We wish to travel to the edge of the Continuum for refueling, then to Aleph-naught, traveling as short a distance as possible. To what point on the edge of the Continuum should we travel?"



(The solution is on page 91.)

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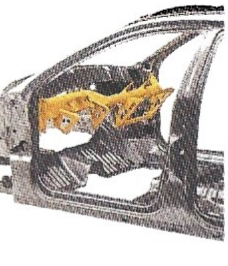

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